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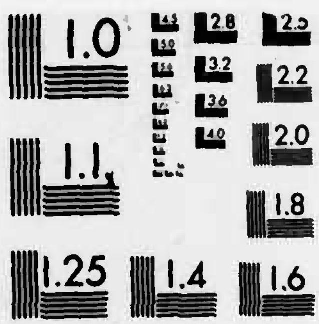

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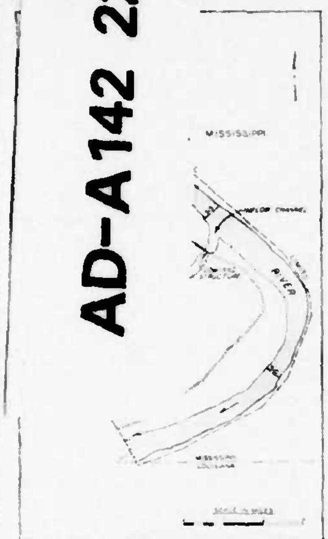

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-84-4

OLD RIVER DIVERSION, MISSISSIPPI RIVER

Report 3
BARGE BARRIER STUDY
Hydraulic Model Investigation

by

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April 1984
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Barges in the inflow channel of the Old River Diversion Low-Sill Structure are of particular concern because of the possibility of their being lodged on the structure and endangering the stability of the already weakened structure. The 1:120-scale undistorted fixed-bed model was used to study the following four types of barge barriers to determine their effectiveness and their effect on the hydraulic conditions of the inflow channel: a spur dike
(Continued)

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20. ABSTRACT (Continued).

system, a vane dike system, an anchored floating barrier, and a pier-supported floating barrier. Also studied was the effect on loose barges of the reduction of discharge through the low-sill structure when an auxiliary structure is used. Results of the studies indicated that only the floating barge barrier would be effective in preventing loose barges from entering the low-sill structure inflow channel and this barrier would require an overbank structure through which flow could pass easily to stop barges floating across the overbank toward the inflow channel during floods. The pier-supported floating barrier would require all piers except the most upstream pier and all floating barrier sections to be designed to withstand equal impact based on the angle of approach of an unpowered tow. The most upstream pier should be designed to withstand the total impact force from a barge tow during a flood with sufficient overbank depth to provide flotation. An auxiliary low-sill structure to carry a portion of the flow diverted from the Mississippi River would reduce, but not eliminate, the likelihood of loose barges entering the low-sill inflow channel and becoming lodged on the low-sill structure.

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PREFACE

The model investigation reported herein was tentatively authorized by Mr. J. H. Douma of the Office, Chief of Engineers (OCE), in a telephone conversation 9 May 1973 and confirmed in a letter dated 14 June 1973 to the Division Engineer, U. S. Army Engineer Division, Lower Mississippi Valley (LMVD). This portion of the study was conducted for the U. S. Army Engineer District, New Orleans (LMN), in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period May 1976 to April 1977.

During the course of the model study, LMN was kept informed of the progress of the study through monthly reports and interim reports of special results. In addition, representatives of OCE, LMVD, and LMN visited the WES at intervals to observe model tests and discuss test results.

The investigation was conducted under the general supervision of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and under the direct supervision of Mr. J. E. Glover, Chief of the Waterways Division. The engineers in immediate charge of the model were Mr. B. K. Melton (retired) and Mr. T. J. Pokrefke, Jr., Chief of the Potamology Branch, assisted by Messrs. C. R. Nickles, C. W. O'Neal, Jr., E. E. Moorehead, B. T. Crawford, and L. Brown. This report was prepared by Messrs. Nickles and Pokrefke.

Commanders and Directors of WES during the course of this investigation and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
miles (U. S. statute)	1.609344	kilometres

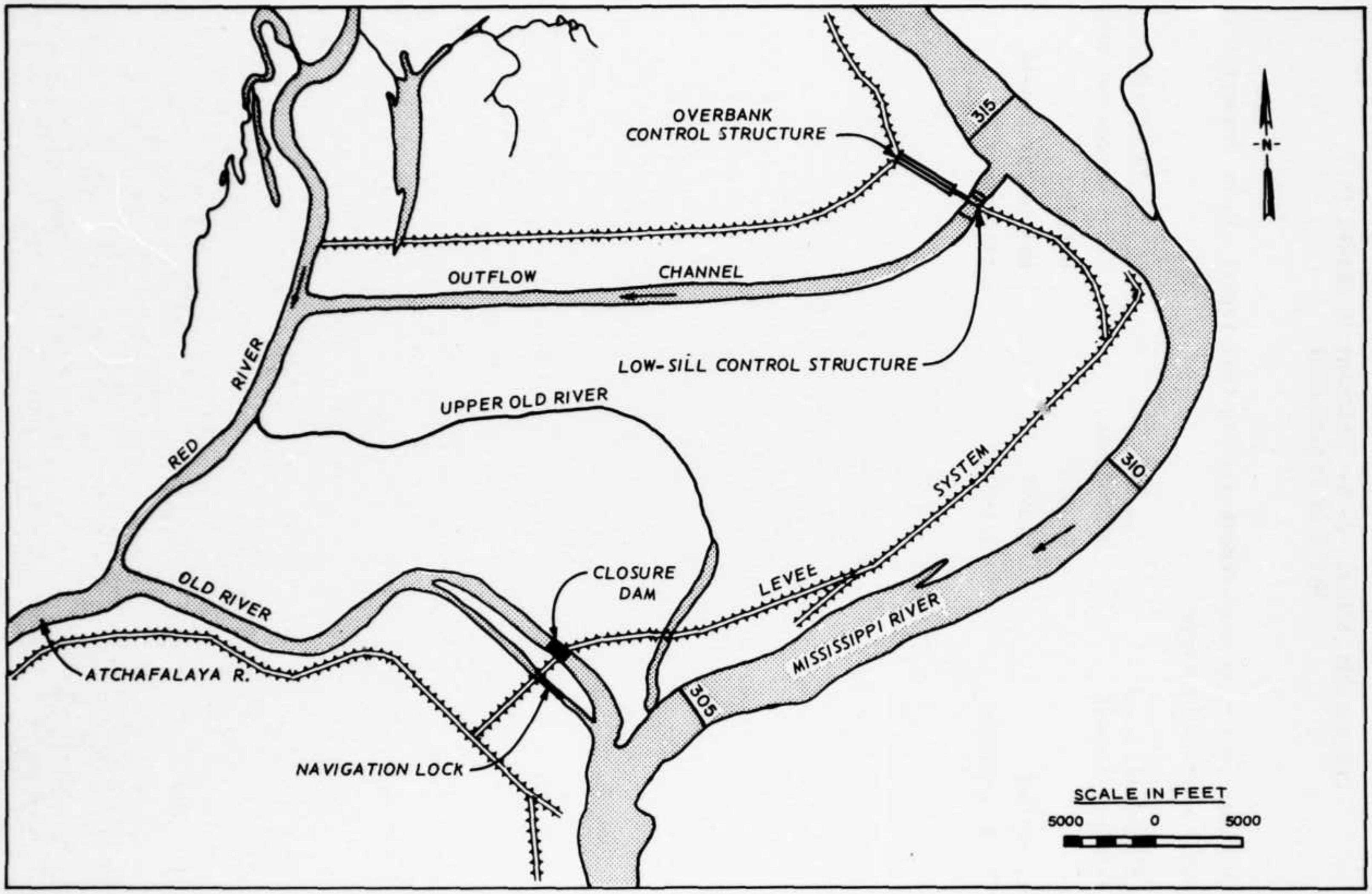

Figure 1. Location map

OLD RIVER DIVERSION, MISSISSIPPI RIVER

BARGE BARRIER STUDY

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. Prior to construction of the Old River control structures, the Atchafalaya River, the principal distributary of the Mississippi River through a short connecting channel, had been increasing in capacity to such an extent as to threaten to divert the Mississippi River through its much shorter and steeper route. In order to control flow from the Mississippi and prevent its capture by the Atchafalaya River, the short connecting channel was closed with a dam and navigation lock, the existing Mississippi River levees above and below the channel were connected, and two control structures within the existing Mississippi levee were constructed at river mile 314.5 AHP. The control structures include a low-sill structure 548.5 ft* long and an overbank structure approximately 3,393 ft long which operates during flood flows (Figure 1). Complete information pertaining to the location and description of the Old River control structures can be found in Report 1.**

2. Upon being placed in operation in 1964, it became evident that particularly the low-sill control structure was susceptible to damage as a result of loose barges being drawn from the Mississippi River toward the structure. In 1964 and 1965, loose barges were drawn into the low-sill structure and impaired operations in both instances for several months. Removal of the barges resulted in high head differentials (due to gate closure required) and reopening of the gates produced high flow velocities and uneven flow patterns that caused scour in the outflow channel. Based on these and other instances, keeping loose barges out of the low-sill structure inflow channel was

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** "Old River Diversion, Mississippi River; Report 1, Introduction, Description, Adjustment and Verification of Models, and Summary of Results" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

determined to be very desirable and a necessary consideration for operation.

Purpose of Study

3. The purpose of the barge barrier studies was to develop a structure which will provide a high degree of assurance that loose barges in the Mississippi River would not enter the inflow channel of the low-sill structure. Loose barges in the inflow channel are of particular concern because of the possibility of their being lodged on the low-sill structure and endangering the stability of the already weakened structure. Loose barges lodged on the structure could cause excessive headwater-tailwater differentials by blocking gate bays or jamming gates so that they cannot be opened as the Mississippi River stage increases. Loose barges lodged on the overbank structure would not create a serious problem because of its great length and resultant minimum decrease in flow-carrying capacity caused by the blockage of any reasonable number of bays.

Model Testing

4. All testing was conducted in the 1:120-scale undistorted fixed-bed model (see Report 1). Figure 2 shows the area reproduced on this model. Two types of barriers were tested--dike systems in the Mississippi River channel and floating barriers at the entrance of the inflow channel. The dike barrier systems consisted of a spur dike system and a vane dike system, which were previously studied to improve the inflow channel hydraulic conditions (see Report 2).* The two floating barriers tested were an anchored barrier and a pier-supported barrier. The anchored barrier consisted of 16 barges anchored in place by cables and the pier-supported barrier consisted of 8 larger barges attached to cylindrical piers.

5. Although not a barge barrier, the use of an auxiliary low-sill structure in conjunction with the existing low-sill structure was studied because a reduction of loose barges entering the low-sill inflow channel could be expected due to the reduced discharge through the low-sill structure. The

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* "Old River Diversion, Mississippi River; Report 2, Mississippi River and Inflow Channel Investigations" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

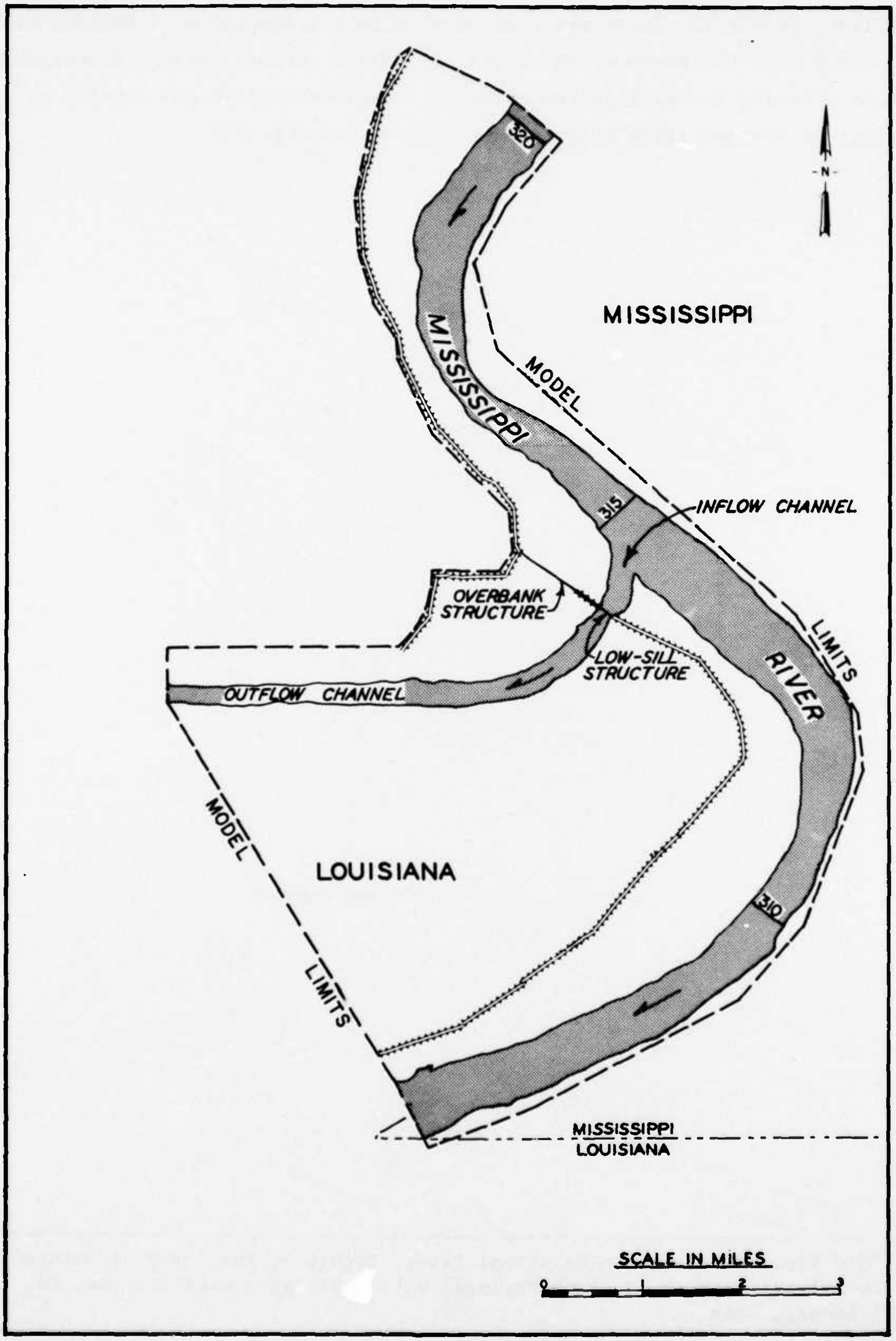

Figure 2. 1:120 undistorted fixed-bed model

auxiliary structure tested was a gated structure independent of the low-sill structure with the mouth of the auxiliary inflow channel located downstream of the existing low-sill inflow channel. Complete details and results of testing of the auxiliary structure are given in Report 7.*

* "Old River Diversion, Mississippi River; Report 7, Auxiliary Structure" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

PART II: TESTS AND RESULTS

Test Procedure

6. Comparisons and effectiveness of all barriers were obtained from time-lapse photographs and visual observations of loose barges. For each test, orifice control operation was used for the low-sill structure. Orifice control operation is a method of operating the low-sill structure with the vertical-lift gates of the structure partially submerged where the flow is passed underneath the gates through an opening below the surface of the water. When the river stages were high enough to allow flow through the overbank structure, 30 gates of a total of 73 gates equally spaced across the structure were opened to maintain the desired distribution of flow between the two structures. The barges were introduced at about mile 316.0 AHP which was believed to be far enough upstream of the inflow channel to be out of the effect of the structures and were allowed to drift downstream with the currents. The barges used for each test were 35 ft wide and 195 ft long with a small battery-operated light on the bow and stern to allow the path of each barge to be traced on a photograph. Barges numbered 1 to 4 were weighted to draft 9 ft and numbers 5 and 6 were partially loaded to draft approximately 6 ft. Each test consisted of six releases of six unattached barges abreast. The relative position of the fully loaded and partially loaded barges was changed from release to release. Preliminary review of test results indicated that barges released more than one-third of the Mississippi River channel width from the right bank were not likely to be drawn into the inflow channel; therefore only barges released in the right descending one-third of the channel were considered for comparing the effectiveness of the various plans.

7. Additional tests were conducted on the most effective barrier to determine its effect on the hydraulics of the inflow channel and to obtain necessary data from which to compute forces required for its design. Velocity and current directions, velocity profiles, velocity cross sections, and water-surface profiles were used to evaluate the barriers' effects on the hydraulics of the inflow channel. Current velocities at key points, the point of impact, and the angle of impact of loose barges were determined for a series of Mississippi River stages to aid in the design of the barrier.

8. The test procedure was modified considerably for tests of the effect

of a proposed auxiliary low-sill structure on the tendency for loose barges to enter the low-sill inflow channel. These changes are described under auxiliary structure tests.

Test Results

Existing conditions

9. Description. Existing conditions with no barriers in place were tested with Mississippi River stages at Knox Landing of 45 and 50 ft NGVD.* A 60-ft stage was also tested with the overbank structure open and with the overbank structure closed.

10. Results. The 60-ft stage with the overbank structure closed produced the greatest incidence of barges entering the inflow channel. All barges released in the right one-third of the Mississippi River channel were drawn into the inflow channel (Photo 1). The 60-ft stage with the overbank structure open reduced to 90 percent the number of loose barges entering the inflow channel, because some of the barges floated onto the overbank and became lodged there or on the overbank structure (Photo 2). The number of loose barges entering the inflow channel was somewhat less for the 45- and 50-ft stages. Of the barges released, approximately 70 percent entered the inflow channel and 30 percent passed the entrance or struck the point at the downstream side of the inflow channel and continued downstream (Photo 3).

Spur dike system

11. Description. The spur dike system consisted of five dikes located near the mouth of the inflow channel (Plate 1). Dikes 1, 2, and 3 were upstream of the entrance at river miles 315.15, 315.0, and 314.85, respectively, and extended from the right bank of the Mississippi River normal to the flow. Dikes 1, 2, and 3 were constructed at el +45 to lengths of approximately 650 ft, 800 ft, and 1000 ft, respectively. Dikes 4 and 5 were located at the downstream side of the inflow channel entrance, river mile 314.45. Dike 4, approximately 800 ft long and constructed at el +45, extended from the bank into the Mississippi River channel and was angled upstream approximately 60 deg to the direction of flow. Dike 5, approximately 475 ft long and at

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* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

the same root location as dike 4, extended into the inflow channel normal to the flow, was constructed at el +45 at its bank end, and sloped to el +10 at its stream end.

12. Results. Generally, this dike system decreased the number of loose barges to enter the inflow channel by approximately one-half. On the 45- and 50-ft stages some barges tended to be trapped in the dike system, but others were deflected past the inflow channel entrance. Approximately 40 percent of the barges were drawn past the end of dike 3 into the inflow channel (Photo 4). For the 60-ft stages with and without operation of the overbank structure, the incidence of loose barges entering the inflow channel was reduced to approximately 50 percent. Barges drifting along the stream ends of dikes 1, 2, and 3 were deflected past the channel, but barges that floated over the dikes entered the inflow channel. With the overbank structure closed, barges drifted across the overbank and into the inflow channel (Photo 5). With the overbank structure open, some loose barges were drawn toward the overbank structure; but others continued to drift across the overbank into the inflow channel (Photo 6).

13. To reduce the number of loose barges floating across the overbank, an additional stone-fill overbank dike was added to the system and tested for both conditions of the 60-ft stage. The dike began at the main-line levee between the low-sill and overbank structures and extended along the right side of the inflow channel at an elevation sufficient to prevent overtopping at Project Flood. The stream end of the dike was sloped to tie into the bank end of dike 3. This overbank dike did not effectively reduce the number of barges entering the inflow channel, because barges drifted riverward along the overbank dike with the current and passed over dike 3, then entered the inflow channel (Photo 7).

Vane dike system

14. Description. The vane dike system consisted of four dikes located near the mouth of the inflow channel (Plate 2). Dikes 1, 2, and 3 were constructed upstream of the inflow channel entrance at river miles 315.2, 314.8, and 314.6, respectively. Dike 4 was constructed at the downstream side of the inflow channel entrance at river mile 314.45. Since the effectiveness of vane dikes decreases greatly when overtopped, the four dikes were constructed to an elevation sufficient to prevent overtopping until the river stage reached an elevation where the overbank structure could be

operated--approximately +55 ft. Dike 1 extended from the right bank riverward and normal to the flow approximately 280 ft, then angled downstream 620 ft at an angle of approximately 45 deg to the flow. Dike 2 was 700 ft long at an angle of approximately 30 deg to the flow. The opening between the upstream end of dike 2 and the downstream end of dike 1 was 450 ft. Dike 3 was 625 ft long at an angle of approximately 15 deg to the flow. The opening between the upstream end of dike 3 and the downstream end of dike 2 was 600 ft. Dike 4 was a spur dike constructed normal to the flow and was approximately 280 ft long.

15. Results. For the vane dike system, a 40-ft stage was tested instead of the 45-ft stage in the previous plan to obtain a wider spread in the stages tested. The probability of loose barges entering the inflow channel for the 40- and 50-ft stages was reduced to approximately 35 percent. Some of the barges entering the channel passed between the vane dikes and entered the inflow channel, while others were trapped in the turbulence behind the vane dikes long enough to be collected (Photo 8). If these barges trapped in the dike system were not captured, they could in time drift from the dike system into the inflow channel, thus increasing the number of incidences of barges entering the inflow channel. For the 60-ft stage with and without the overbank structure in operation, the probability of loose barges entering the inflow channel was reduced to approximately 20 percent. Barges drifting along the stream ends of the dikes were generally swept past the entrance, while barges floating over the dikes were grounded there or drifted between the dikes onto the overbank and ultimately into the low-sill or overbank structure (Photo 9). For river stages that would allow barges to float over the dikes, the probability of barges entering the inflow channel would be much higher than the 20 percent obtained during the tests of the two 60-ft stage conditions. Barges drifting across the overbank into the inflow channel occurred more often when the overbank structure was in operation.

Anchored floating barge barrier

16. Description. The anchored barge barrier was developed through preliminary tests to obtain an alignment wherein loose barges and floating debris would be moved downstream past the entrance to the inflow channel by river currents and would not collect on the barrier or enter the inflow channel. The plan consisted of a 1,990-ft-long floating barrier comprised of individual barges drafting 9 ft and loosely fastened end to end. The upstream

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15. Results. For the vane dike system, a 40-ft stage was tested instead of the 45-ft stage in the previous plan to obtain a wider spread in the stages tested. The probability of loose barges entering the inflow channel for the 40- and 50-ft stages was reduced to approximately 35 percent. Some of the barges entering the channel passed between the vane dikes and entered the inflow channel, while others were trapped in the turbulence behind the vane dikes long enough to be collected (Photo 8). If these barges trapped in the dike system were not captured, they could in time drift from the dike system into the inflow channel, thus increasing the number of incidences of barges entering the inflow channel. For the 60-ft stage with and without the overbank structure in operation, the probability of loose barges entering the inflow channel was reduced to approximately 20 percent. Barges drifting along the stream ends of the dikes were generally swept past the entrance, while barges floating over the dikes were grounded there or drifted between the dikes onto the overbank and ultimately into the low-sill or overbank structure (Photo 9). For river stages that would allow barges to float over the dikes, the probability of barges entering the inflow channel would be much higher than the 20 percent obtained during the tests of the two 60-ft stage conditions. Barges drifting across the overbank into the inflow channel occurred more often when the overbank structure was in operation.

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end of the barrier was fixed to the bank, and a cable was provided at the downstream end of each barge and run to an anchor in the river channel. These cables were adjusted with changes in stage so that the barrier was kept straight and in the same location for all stages tested. The barrier began at a point on the right bank of the Mississippi River immediately upstream of the inflow channel, made an angle of approximately 10 deg with the bank line, and extended to a point 2,730 ft riverward of and along the center line of the low-sill structure. With this alignment, the barrier extended across approximately three-quarters of the inflow channel entrance.

17. Results. The anchored barge barrier was tested at Mississippi River headwater stages at Knox Landing of 20 and 50 ft NGVD, and Project Flood. Photographs and visual observation of loose barges indicated the barrier to be very effective in reducing the incidence of barges entering the inflow channel (Photo 10). For all flows tested, less than one percent of the loose barges entered the inflow channel. However, tests conducted for the Project Flood showed that barges moving along the right bank line tended to bypass the barrier upstream and enter the inflow channel from the overbank (Photo 11).

Pier-supported floating barge barrier

18. Description. The anchor cables on a previous prototype barge barrier located at the entrance to the low-sill structure inflow channel tended to collect debris; therefore a pier-supported floating barge barrier, designed by the U. S. Army Engineer District, New Orleans, was proposed. The barrier was comprised of eight specially designed barges supported by nine cylindrical piers, spaced 250 ft on center (Plate 3). Each barge was 250 ft long, 50 ft wide, and 12 ft high. When in place, the barges drafted 5 ft. The piers were 33 ft in diameter and were located on the landside of the barges. The piers and barges were built so that the barges could move vertically with changes in the Mississippi River stage. The barrier began at a point on the right bank of the Mississippi River immediately upstream of the entrance of the inflow channel, approximately river mile 314.9, and extended downstream and slightly riverward for 2,000 ft to a point 250 ft upstream of the center line of the low-sill structure and 2,730 ft riverward of the structure. The alignment of the barrier intersected the center line of the low-sill structure at an angle of 95°-23'. This barrier blocked approximately three-quarters of the inflow channel entrance, which was the same as the anchored barrier previously tested.

19. Results. Loose barge tests were conducted on the pier-supported barge barrier for low-sill structure headwater stages of 16, 24, 28, 32, 40, and 46.6 ft (bank-full), 1973 Flood, and Project Flood to evaluate the plan's effectiveness. For the bank-full and below stages, all of the loose barges were deflected past the entrance of the inflow channel (Photos 12 and 13). For the 1973 Flood and Project Flood, all of the loose barges drifting on the riverside of the barrier were deflected past the entrance, while those barges drifting along the right river bank line either hit the upstream end of the barrier or drifted onto the overbank upstream of the barrier. These barges tended to continue on into the inflow channel or become lodged on the overbank structure (Photo 14).

20. Since the pier-supported barge barrier produced a very high degree of assurance that loose barges would not enter the inflow channel, additional tests were conducted to determine the barrier's effect on the hydraulic conditions of the inflow channel. These tests evaluated water-surface profiles, velocity and current directions, and point velocities in the inflow channel. Water-surface profiles and velocities and current directions were obtained for low-sill structure headwater stages of 16, 24, 28, 32, and 40 ft for conditions of no barrier, and the barrier in place with the low-sill structure in orifice operation. Water-surface profiles indicated no change in the water surface of the inflow channel, gages 10 and 12 (Plate 4 and Table 1). Comparison of water-surface profiles for the 24- and 40-ft stages indicates that no significant change occurred in the Mississippi River or Old River Diversion channels with the barrier in place. The barge barrier caused no significant change in the velocities and current directions in the inflow channel. Results of orifice control operation, shown in Plates 5-8, indicated the maximum velocities 500 ft upstream of the low-sill structure to be 3.6 and 5.5 fps for the 24- and 40-ft stages, respectively, for no barrier, and 3.4 and 5.3 fps, respectively, for the barrier in place. Point velocities at 0.6 depth and bottom depth were obtained in the inflow channel for bank-full, 1973 Flood crest, and Project Flood crest stages with and without the barrier in place with all the low-sill and overbank structures gates open. Results, shown in Plates 9-11, indicated maximum 0.6-depth velocities at 650 ft upstream of the low-sill structure to be 6.3, 5.4, and 5.7 fps for the bank-full, 1973 Flood, and Project Flood stages, respectively, for no barrier and 6.7, 5.1, and 5.8 fps with the barrier in place.

21. Three additional tests were conducted for the pier-supported barrier to obtain data to aid in the structural design of the barges and piers. Vertical velocity profiles at the pier locations were obtained for Mississippi River stages of bank-full, 1973 Flood crest, and Project Flood crest to determine the velocities for load calculation on the piers. Vertical velocity profiles, Plate 12, indicated that the higher velocities occurred at the locations of piers 5, 6, and 7, and ranged from about 6 fps for the bank-full stage to about 10.5 to 11 fps for the Project Flood crest. The second test consisted of releasing loose barges upstream of the inflow channel and allowing them to drift downstream toward the barge barrier to determine the probability of a particular barge of the barrier being struck by a loose barge. Ten runs of twenty barges per run were conducted for each of the three flows tested. Results of the test, shown in Table 2, showed the probability of some barge in the barrier being struck to be 70, 80 and 62 percent for the bank-full stage, 1973 Flood crest, and Project Flood crest, respectively. The most likely individual barge to be hit was barge 5 for the bank-full and 1973 Flood crest stage and barge 1 for the Project Flood crest stage. The least likely barge to be hit was barge 1 for the bank-full stage, barge 7 for the 1973 Flood crest, and barges 5, 6, 7, and 8 for the Project Flood crest. All barges in the barrier were hit by loose barges during each test. Additional loose barge flotilla tests using various barge configurations that drafted 9 ft were also conducted for the bank-full, 1973 Flood crest, and Project Flood crest stages to determine the force exerted on the barrier from being hit by drifting barge flotillas. The angle of approach was measured during the test so that the force could be computed by multiplying the mass of the barges times the velocity of approach times the sine of the angle of approach ($F = mV \sin a$). The flotilla schemes used for each flow were a single barge, three barges wide - two barges long, two barges wide - three barges long, one barge wide - six barges long, five barges wide - one barge long, five barges wide - two barges long, two barges wide - five barges long, six barges wide - two barges long, and three barges wide - four barges long. The maximum force on the barrier would be imposed with either the six barges wide - two barges long or the three barges wide - four barges long grouping for each flow tested since the greater mass of the twelve barge combination overshadowed the difference in angle of approach. Results of the test (Plates 13 and 14) indicated that the maximum angle of approach for the

Project Flood, 1973 Flood crest, and bank-full crest stage was 24 deg, 26 deg, and 24 deg, respectively. The maximum velocity of approach was 7.0 fps, 9.2 fps, and 10.2 fps, respectively. These test results indicated that the most upstream pier (No. 1) could be struck directly by a barge flotilla when there was sufficient overbank depth. In this case, there would be no angle of approach; therefore it would be possible for the pier to receive the total initial force on impact if the point of impact was aligned with the flotilla center of gravity.

22. Tests were also conducted to determine the velocities that could be expected to occur during construction of the piers. The tests consisted of obtaining point velocities at 0.6 depth and near the bottom at each pier location and 50 ft upstream, downstream, and on each side of the pier for low-sill structure headwater stages of 16, 24, 28, 32, and 40 ft. Test results, shown in Plate 15, indicate that maximum velocities of 6.8 and 6.9 fps occurred on the downstream side of piers 7 and 8, respectively, for the 40-ft stage.

Auxiliary structure

23. Description. Loose barge tests were conducted with the proposed auxiliary low-sill structure in place. The tests consisted of determining the probability of a loose barge entering the low-sill structure inflow channel for conditions of no flow through the auxiliary structure and three different distributions of flow between the two structures. Mississippi River stages at Knox Landing used for each test were 24 and 50 ft and Project Flood. The discharge distribution between the structures was based on the diversion ratio curves that divided the low-sill structure discharge used in the previous tests between the auxiliary and low-sill structures. Discharge diversion ratios 1, 2, and 3 are shown in Plate 16 as a plot of Knox Landing stage versus the auxiliary structure discharge as a percentage of the total diverted discharge. Based on this curve, the following diverted discharges for the low-sill and auxiliary structures were required for the loose barge tests:

Knox Landing Stage ft NGVD	Discharge, cfs					
	Diversion Ratio 1		Diversion Ratio 2		Diversion Ratio 3	
	Low Sill	Auxiliary	Low Sill	Auxiliary	Low Sill	Auxiliary
24	39,800	30,200	51,700	18,300	31,700	38,300
50	155,500	94,500	192,500	57,500	127,500	122,500
68.8*	192,200	107,800	240,000	60,000	163,600	136,400

* Project Flood

On the Project Flood, the specified discharge through the overbank structure was 320,000 cfs for all diversion ratios. For diversion ratios 1 and 2 tests, the entrance of the auxiliary low-sill structure inflow channel was at mile 311.7 AHP; and for diversion ratio 3 tests, the entrance was at mile 312.8 AHP (Plates 17 and 18). For these tests, the breakup of the tow was assumed about 1 mile farther upstream at mile 317.5 AHP and from a 10-barge configuration rather than the six barges abreast used with other barge barrier tests. The landward edge of the tow was 100 ft from the right bank line at breakup. Ten repetitions each of 10-barge partially loaded tows and 10-barge fully loaded tows were used for the test sample. Loaded barges drafted 9 ft and partially loaded barges drafted 6 ft. Since the test conditions were changed, it was necessary to repeat tests with existing conditions to obtain a basis for comparing the effect of auxiliary structure operation.

24. Results. For existing conditions, test results indicated that 63, 50, and 77 percent of the loaded barges and 82, 62, and 79 percent of the partially loaded barges entered the low-sill structure inflow channel for the 24-ft, 50-ft, and Project Flood stages, respectively (Table 3). For the condition of ratio 1 flow distribution, test results indicated that 17, 32, and 27 percent of the loaded barges and 12, 22, and 24 percent of the partially loaded barges entered the inflow channel, respectively, for the same flows. For the condition of ratio 2 flow distribution, the percentages of loose barges entering the inflow channel, respectively, for the flows tested were 36, 54, and 29 percent of the loaded barges and 42, 60, and 33 percent of the partially loaded barges. For the condition of ratio 3 flow distribution, the percentages were 38, 24, and 30 percent of the loaded barges and 43, 32, and 15 percent of the partially loaded barges.

PART III: DISCUSSION OF RESULTS AND CONCLUSIONS

Limitations of Model Results

25. Analysis of the results of this investigation is based on a study of the effects of various barge barriers and an auxiliary structure on currents that affect loose barges, water-surface elevations, current directions, and velocities. In evaluating test results, it should be considered that small changes in loose barge float patterns, current directions, and velocities are not necessarily changes produced by the barge barrier, because several barges or floats introduced at the same point may follow different paths and move at somewhat different velocities due to pulsating currents or eddies, or possibly due to slight wind gusts since this is an outdoor model. In addition, the test sample to determine the incidence of loose barges entering the low-sill structure inflow channel was not large enough to make an exact determination and should be regarded as only a relative indication of the effectiveness of the various plans. Velocities and current directions shown in the plates were obtained with floats submerged to the depth of a loaded barge (9 ft prototype). Point velocities shown in the plates are average velocities obtained over a period of time with a cup meter. The point velocities at bottom depth are indicative of velocities near the bottom, but not on the bottom because the design of meters used will not permit a velocity to be obtained lower than approximately 5 ft above the riverbed.

26. The small scale of the model made it difficult to measure water-surface elevations within an accuracy greater than ± 0.1 ft prototype. Velocities and current directions were based on steady flows and would be somewhat different with varying flows, particularly when a hydrograph with rising and falling stages is considered. The model was of the fixed-bed type and was not designed to reproduce any sediment movement that might occur in the prototype; therefore changes in channel configurations resulting from scour and deposition were not reflected in the model results.

Summary of Results and Conclusions

27. The following indications and conclusions were developed during the investigation:

a. Without some type of preventive structure, a loose barge drifting near the right bank of the Mississippi River during stages above bank-full would enter the inflow channel approximately 90 percent of the time when the overbank structure was open and 100 percent when the overbank structure was closed; for stages below bank-full, the percentage would be somewhat less, approximately 70 percent.

b. The spur dike system would reduce the incidence of loose barges entering the inflow channel to approximately 40 percent for below bank-full stages and to approximately 50 percent for the 60-ft stage with and without the overbank structure open.

c. The vane dike system reduced the number of loose barge incidences to 35 percent for flows that would not overtop the dikes and 20 percent for flows that would overtop the dikes. Some loose barges would become trapped in the dike field, and if not captured would drift into the inflow channel.

d. The rock overbank dike would not significantly reduce the loose barges from entering the inflow from across the overbank, because barges would be swept riverward around the river end of the dike and still enter the channel.

e. Though not tested, a permeable structure offering little resistance to flow in place of the stone-fill dike would probably allow the loose barges to become lodged on the structure and held in place by the currents, and thus more effectively limit loose barges entering the inflow channel from across the overbank during flood flows.

f. The anchored floating barge barrier reduced the incidence of loose barges entering the inflow channel to less than 1 percent from riverside of the barrier. During flood flow, approximately 10 percent of the barges would bypass the barrier by floating across the overbank and enter the inflow channel. Anchor cables would have a tendency to collect debris.

g. The pier-supported floating barge barrier produced the same high degree of assurance that loose barges would not enter the inflow channel as the anchored barrier.

h. The pier-supported barrier produced no changes in the hydraulic conditions in the inflow channel.

i. Impact investigations indicated that equal force of impact on the pier-supported barrier could occur at any point on the barrier except for the upstream pier; thus all barges and all other piers would have to be designed to withstand an impact force based on the maximum approach angle of a downbound tow and velocity of the current.

j. Special design considerations would have to be given the most upstream pier of the pier-supported barrier, because this pier could receive the total direct impact force of a barge flotilla.

k. Diverting a part of the flow from the low-sill structure to an auxiliary structure would significantly reduce the probability of loose barges entering the low-sill structure inflow channel.

Table 1

Water-Surface Elevations

Pier-Supported Floating Barge Barrier

Gage No.	Low-Sill Structure, Orifice Control: 24-ft Headwater Stage, Miss. River Discharge 298,000 cfs, Old River Discharge 89,000 cfs — Without Barrier	With Barrier	40-ft Headwater Stage, Miss. River Discharge 744,000 cfs, Old River Discharge 170,000 cfs — Without Barrier	With Barrier
1	24.1	24.1	40.6	40.7
2	24.0	24.0	40.3	40.5
3	24.0	24.0	40.2	40.3
4	24.0	24.0	40.0	40.0
5	24.0	24.0	39.8	39.9
6	24.1	23.9	39.9	40.0
9	24.2	24.1	40.1	40.1
10	24.1	24.1	40.1	40.2
11	24.1	24.1	40.0	40.1
12	24.0	24.0	40.0	40.0
13	12.1	12.0	26.2	26.1
14	12.0	11.8	26.2	26.1
15	24.1	23.9	39.8	39.8
16	23.9	23.7	39.7	39.7
17	23.7	23.6	39.6	39.7
18	23.4	23.3	39.3	39.3
19	23.3	23.2	39.1	39.1
20	23.3	23.2	39.1	39.2
21	23.2	23.1	39.0	39.0
23	23.2	23.2	38.8	38.9
24	23.2	23.2	38.7	38.7
25	23.1	23.0	38.6	38.6
26	23.0	22.8	38.4	38.4
27	22.9	22.8	38.4	38.4
28	22.9	22.7	38.2	38.2
29	22.8	22.6	38.1	38.1
30	22.7	22.6	38.0	38.2
31	22.7	22.6	38.0	38.1
32	11.5	11.4	26.0	26.0
33	11.0	10.9	25.6	25.6
34	10.8	10.2	25.2	25.2
35	10.0	9.9	25.1	25.1
36	9.8	9.7	24.9	24.9

Table 2

Probability of Impact with Barrier

Pier-Supported Floating Barge Barrier

Barrier Barge No.	Bank-Full Stage percent	1973 Flood Crest percent	Project Flood Crest percent
Any barge	70	80	62
1	2	6	15
2	6	10	9
3	6	13	6
4	10	12	12
5	18	14	5
6	8	12	5
7	12	3	5
8	8	10	5

Note: Percentages based on a total of 200 loose barges. Barrier barges numbered from upstream.

Table 3

Probability of a Loose Barge Entering Low-Sill Inflow Channel

with Auxiliary Structure Operational

Head-water Stage, ft	Existing Condition of Barges		Flow Diversion					
			Ratio 1 percent		Ratio 2 percent		Ratio 3 percent	
	Loaded	Un-loaded	Loaded	Un-loaded	Loaded	Un-loaded	Loaded	Un-loaded
24	63	82	17	12	36	42	38	43
50	50	62	32	22	54	60	24	32
Project Flood	77	79	27	24	29	33	30	25

Note: Each percentage based on a total of 100 loose barges. The loaded barges drafted 9 ft and the unloaded barges drafted 6 ft.

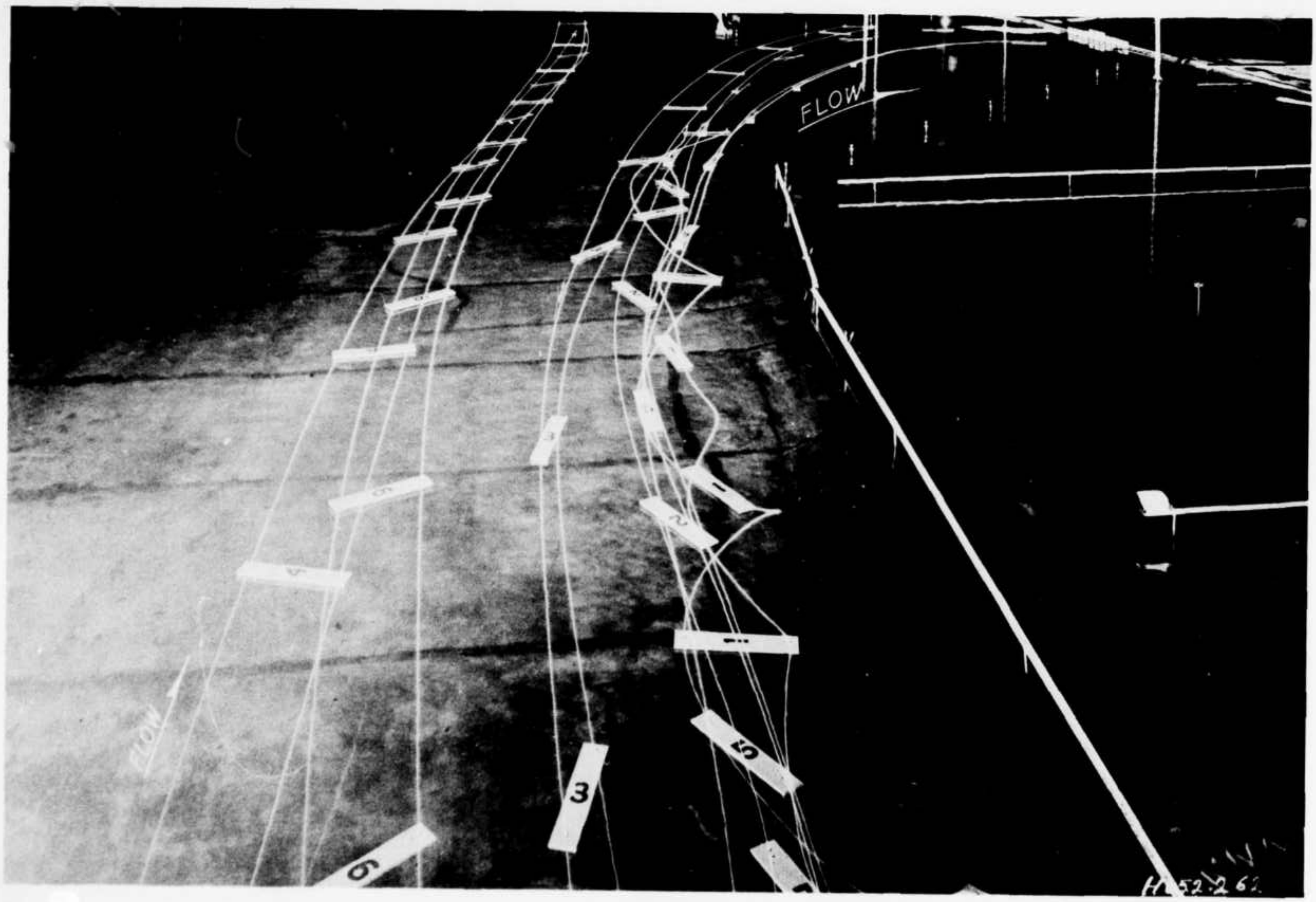


Photo 1. 60-ft stage, orifice control, overbank structure closed

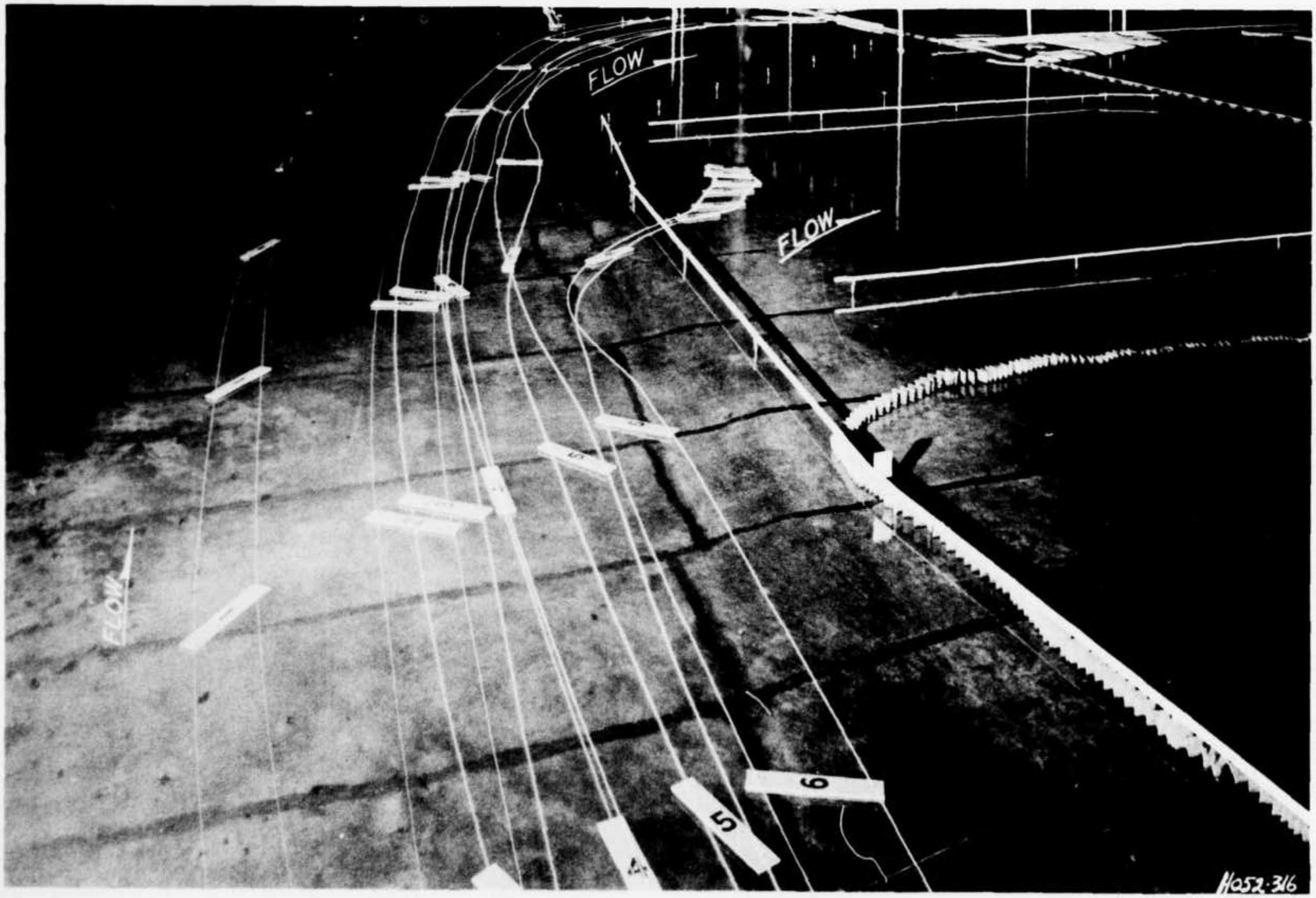


Photo 2. 60-ft stage, orifice control, overbank structure open

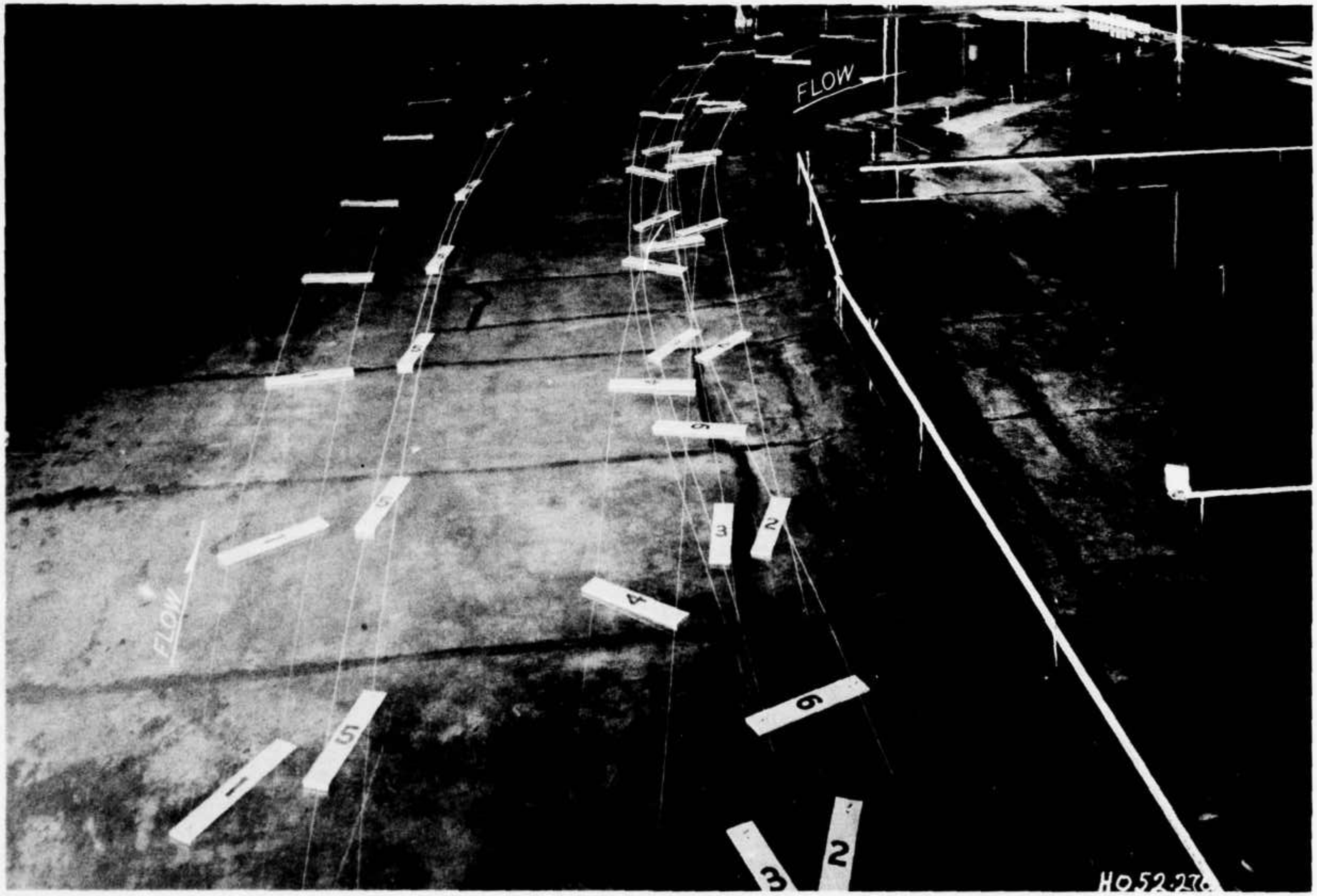


Photo 3. 45-ft stage

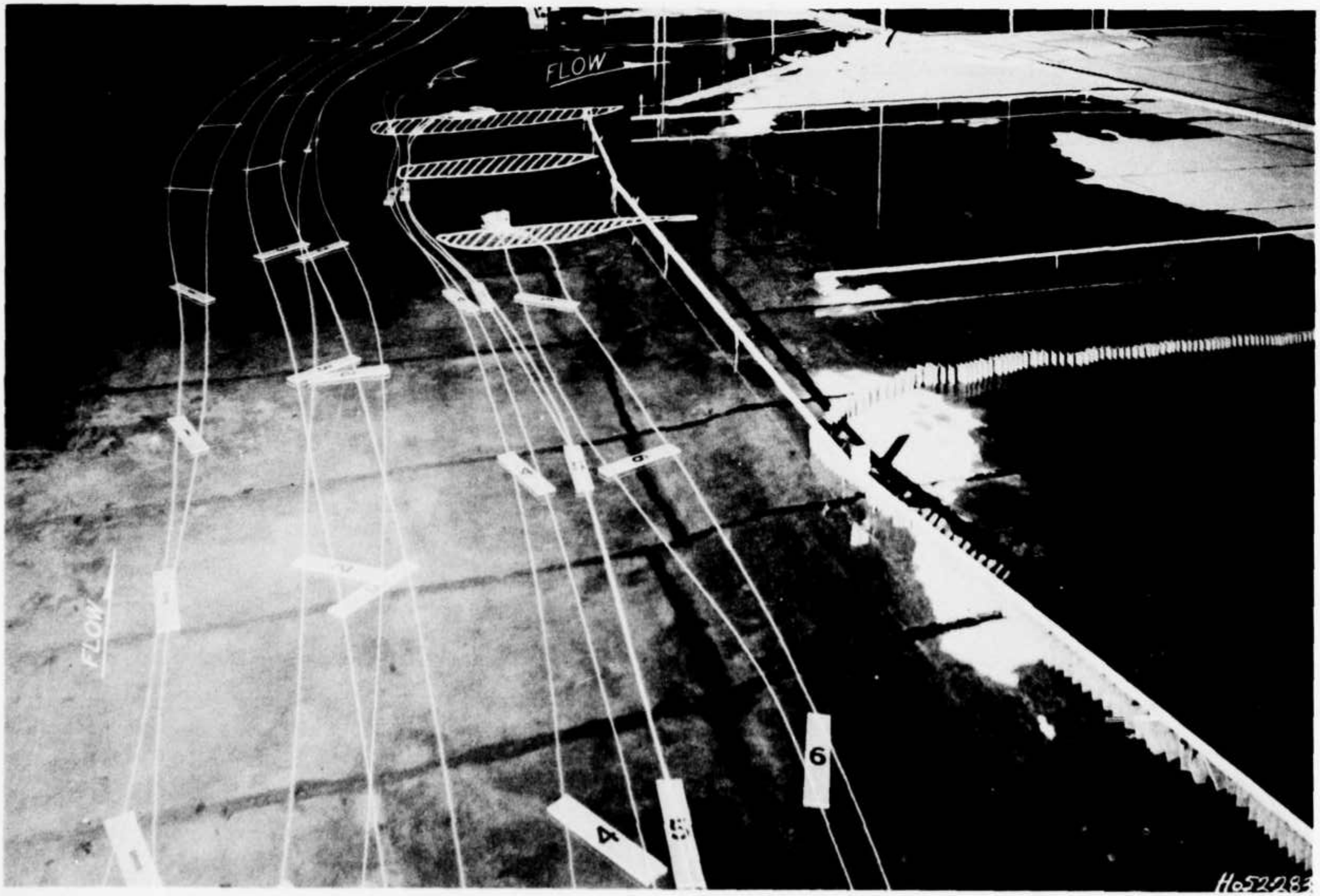


Photo 4. Spur dike barrier, 50-ft stage

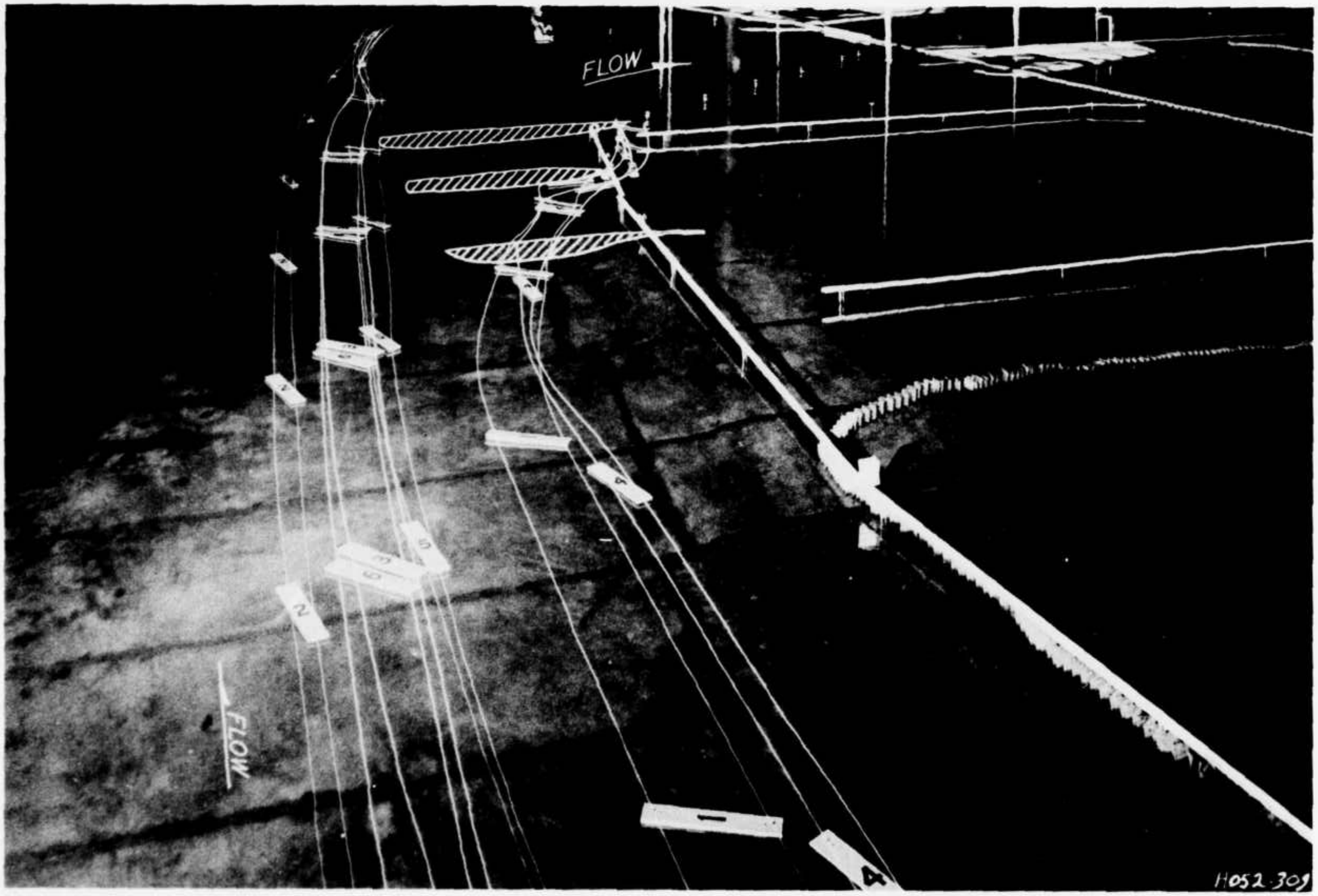


Photo 5. Spur dike barrier, 60-ft stage, overbank structure closed

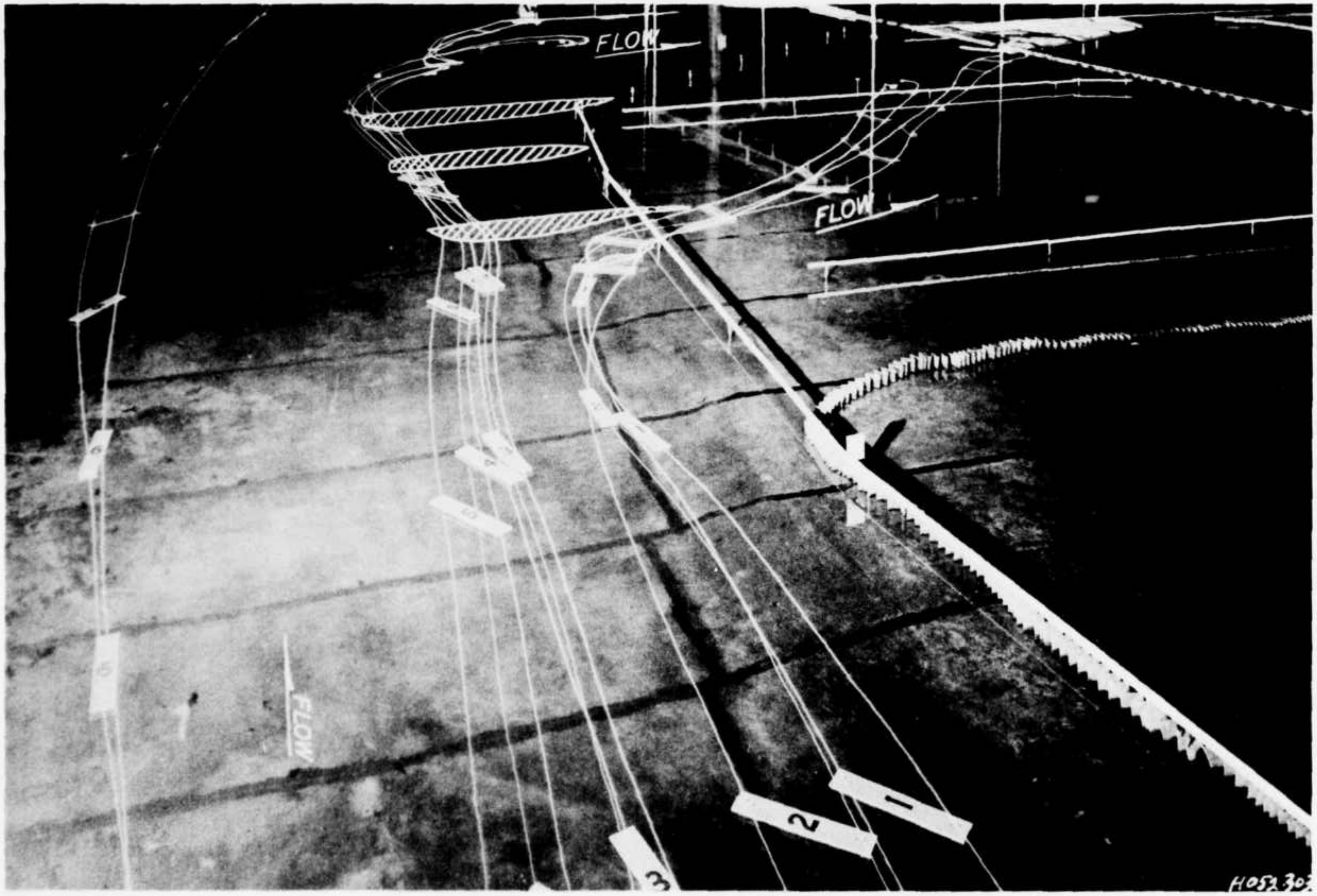


Photo 6. Spur dike barrier, 60-ft stage, overbank structure open

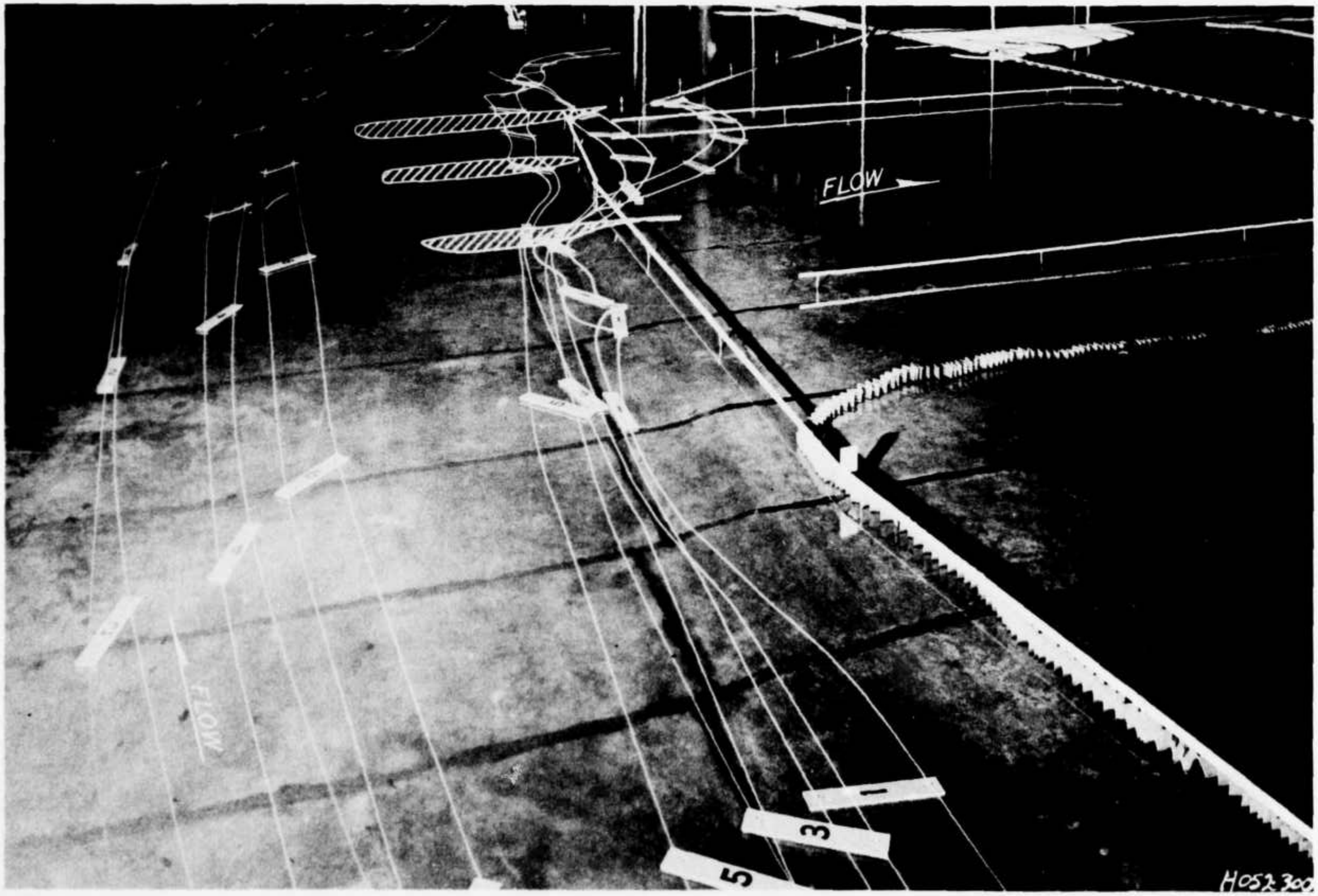


Photo 7. Spur dike barrier with the overbank dike, 60-ft stage, overbank structure open

Photo 8. Vane dike barrier, 40-ft stage

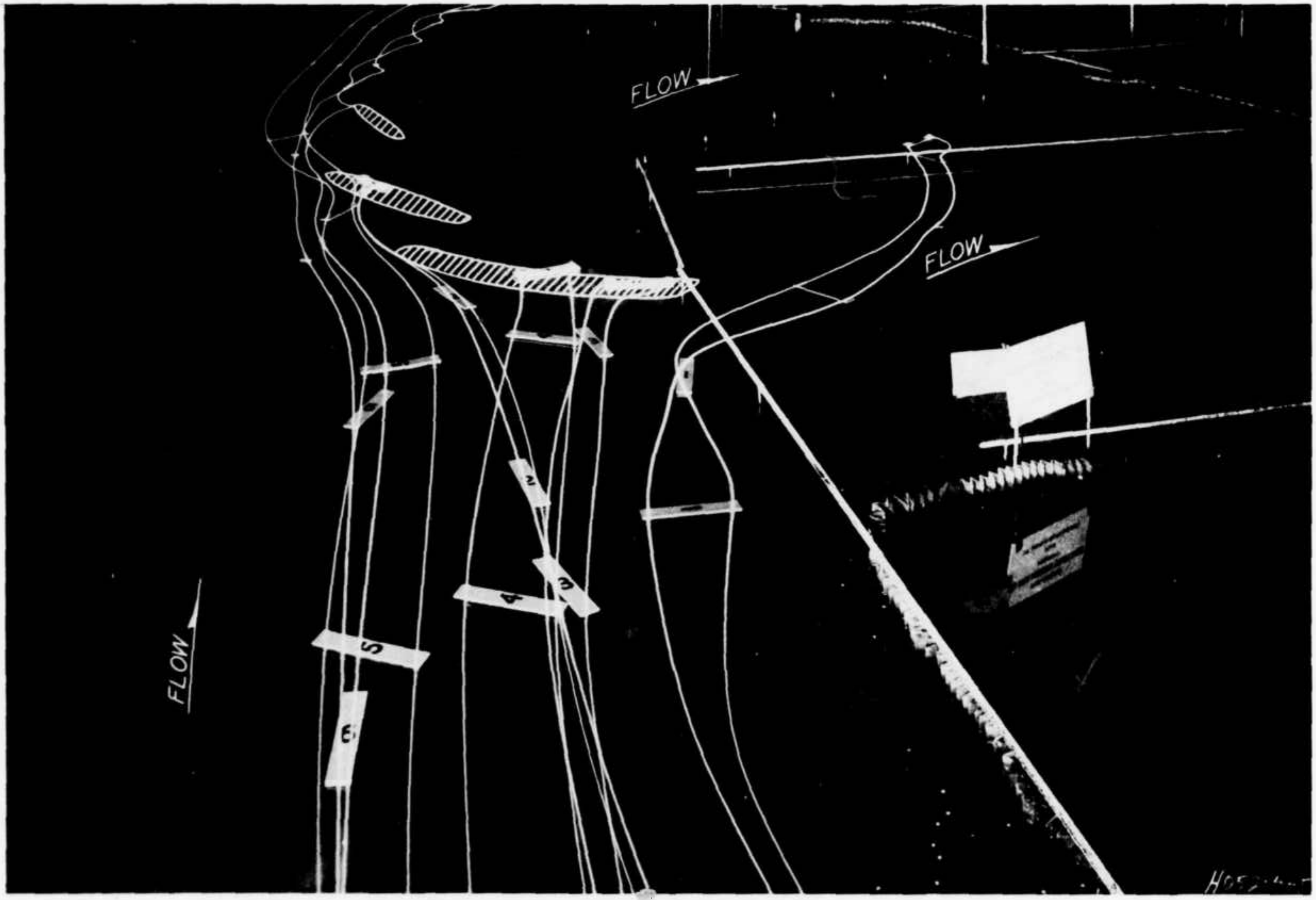


Photo 9. Vane dike barrier, 60-ft stage, overbank structure open

Photo 10. Anchored floating barge barrier, 20-ft stage

Photo 11. Anchored floating barge barrier, Project Flood

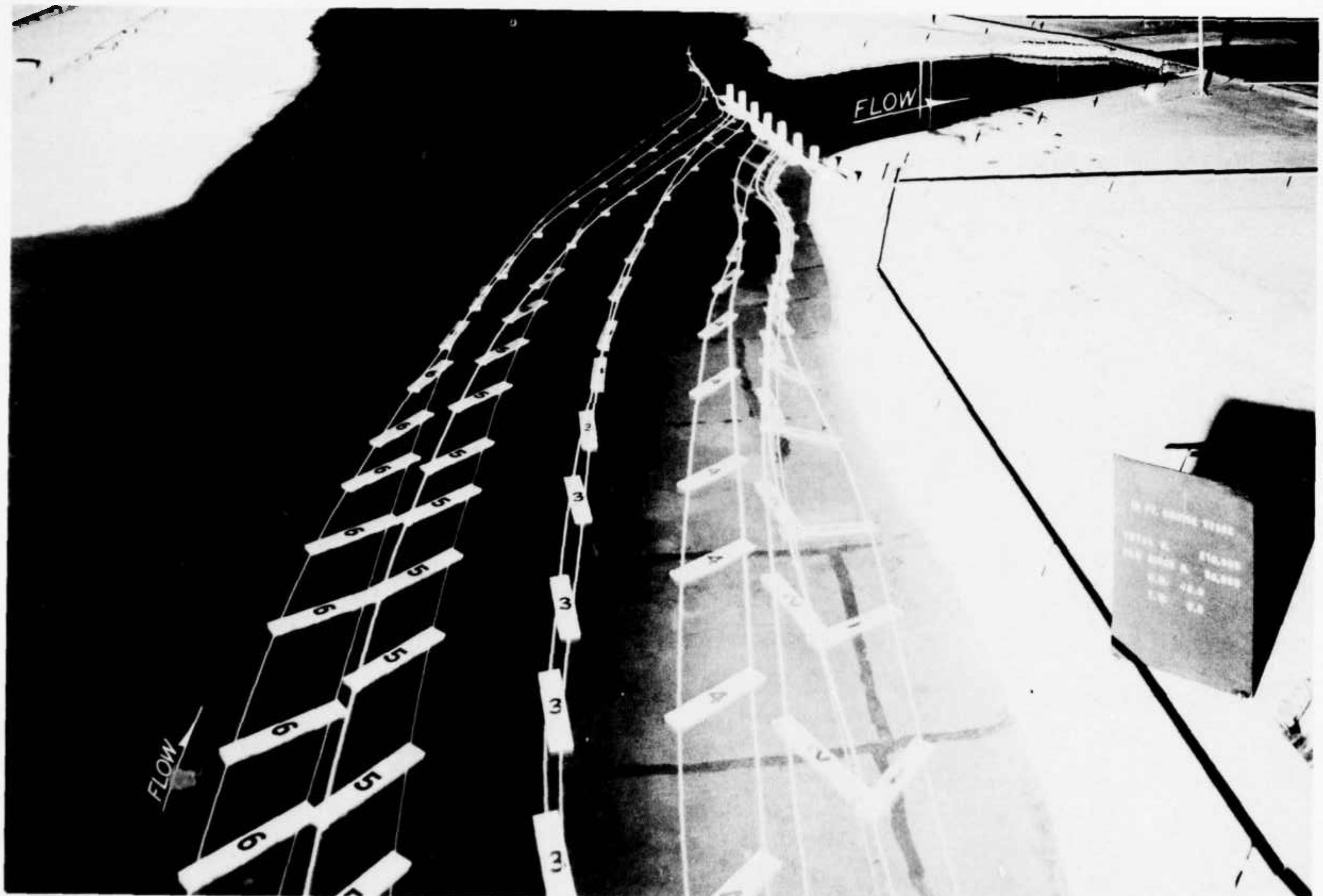


Photo 12. Pier-supported floating barge barrier, 16-ft stage

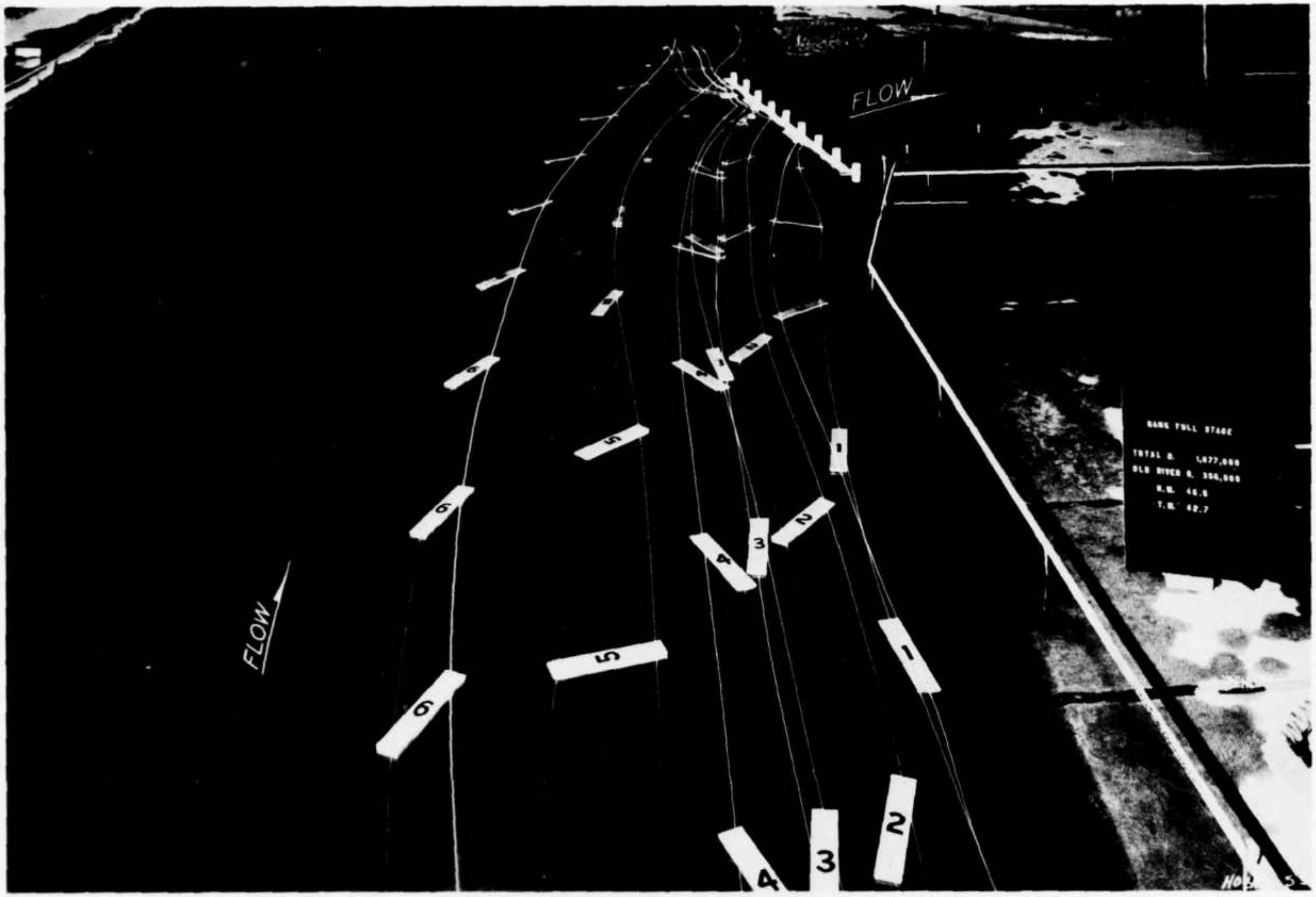


Photo 13. Pier-supported floating barge barrier, 46.6-ft (bank-full) stage

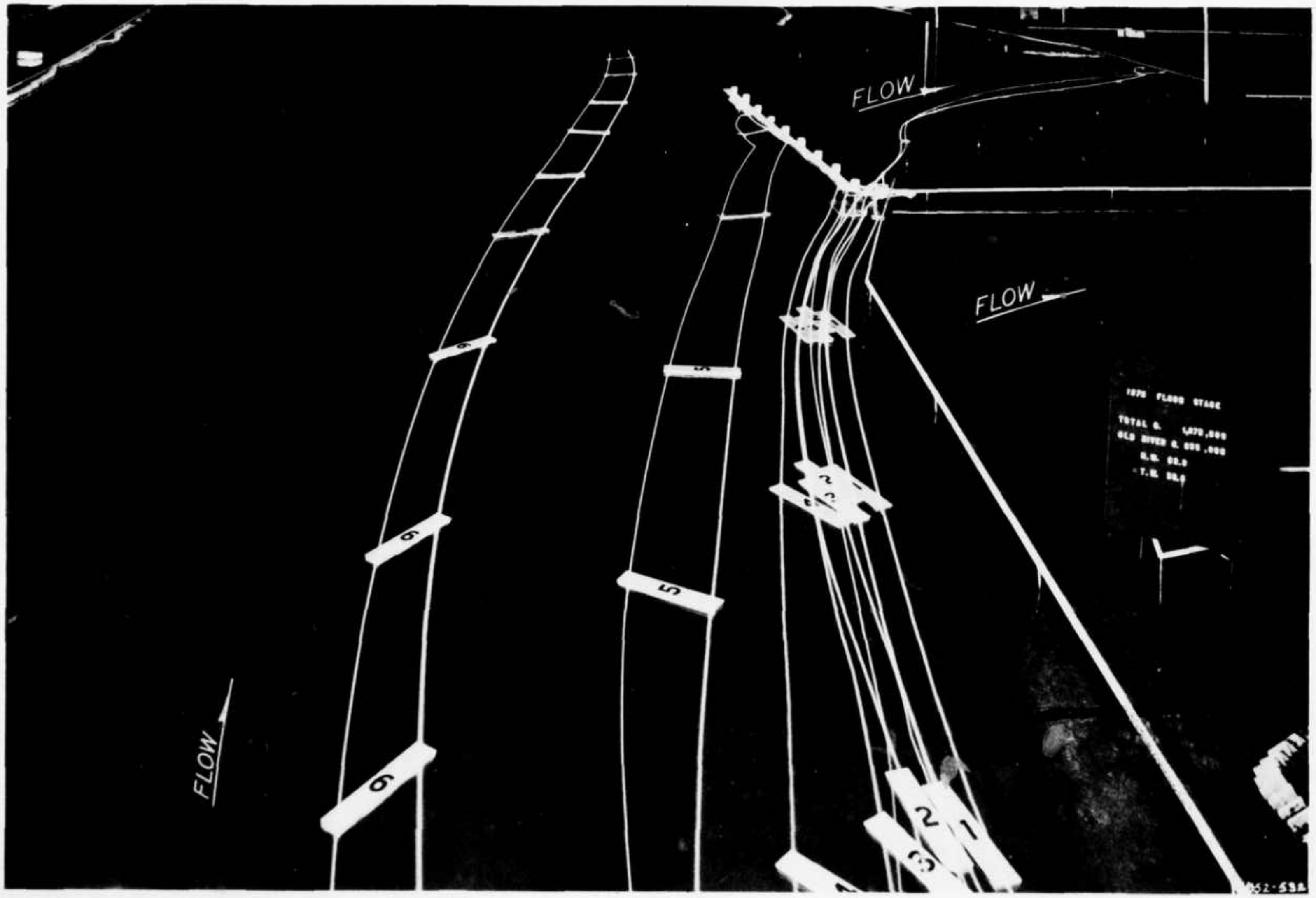
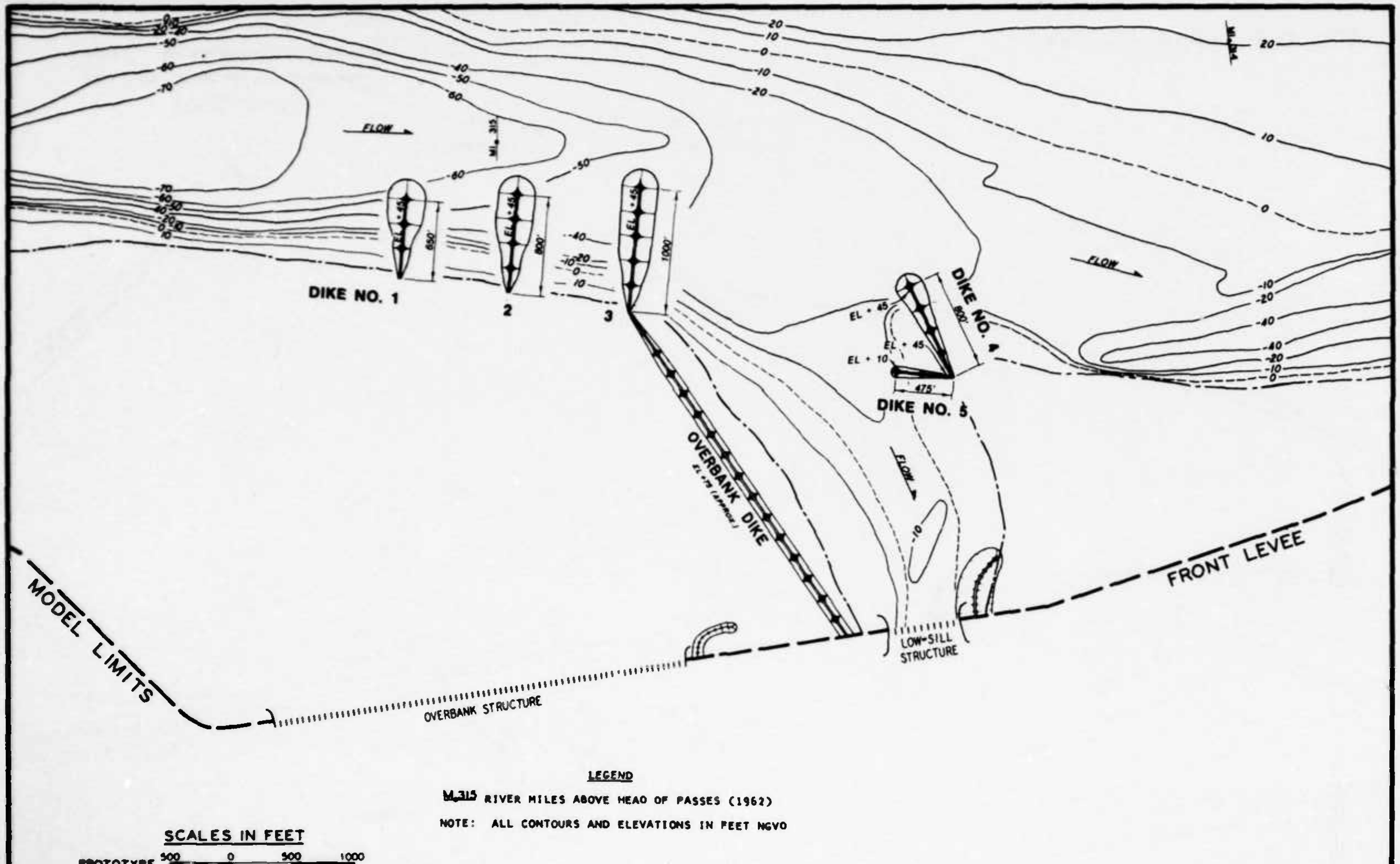
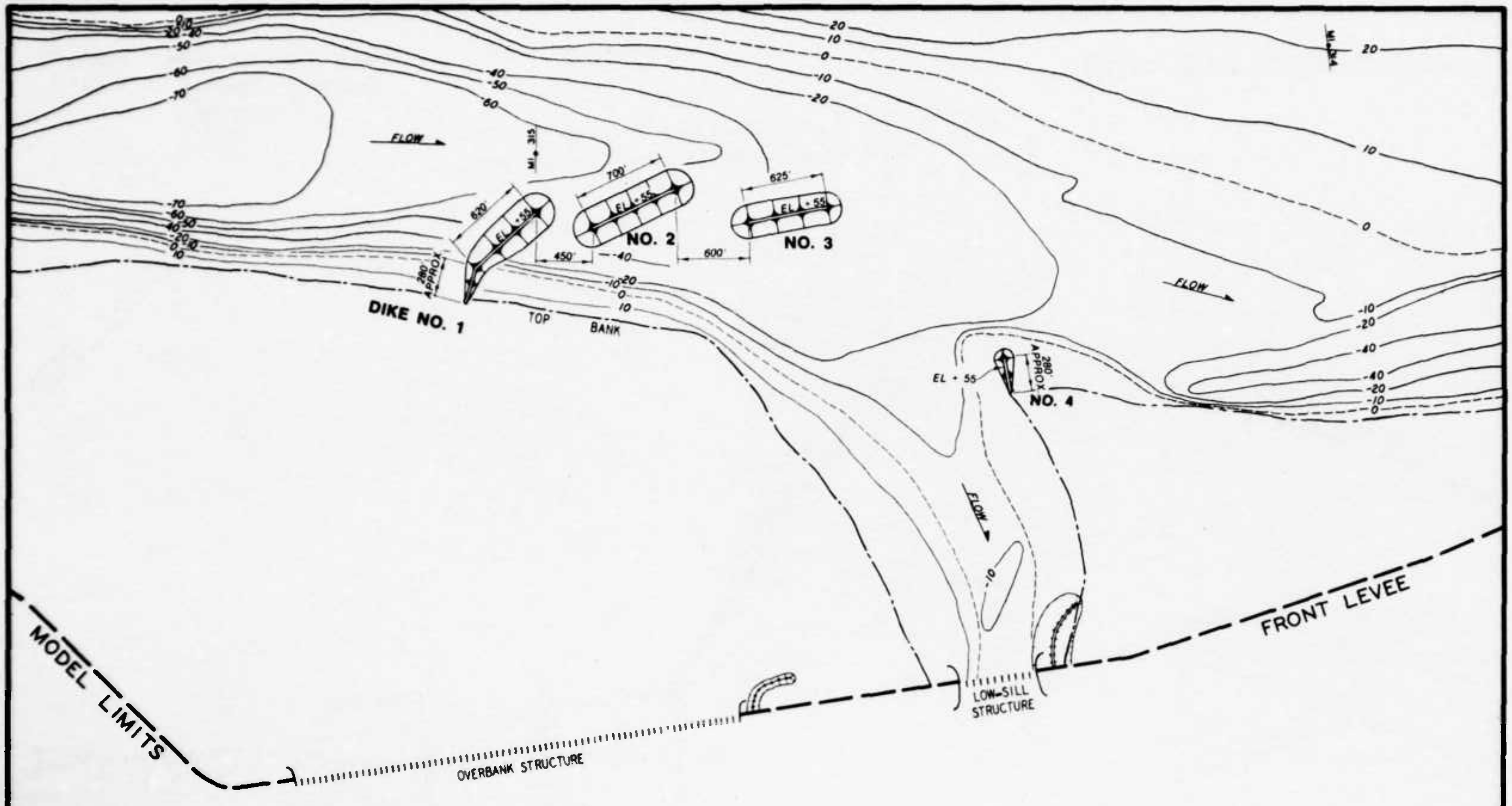


Photo 14. Pier-supported floating barge barrier, 1973 Flood crest



SPUR DIKE SYSTEM PLAN

PLATE 2



LEGEND

M. 315 RIVER MILES ABOVE HEAD OF PASSES (1962)

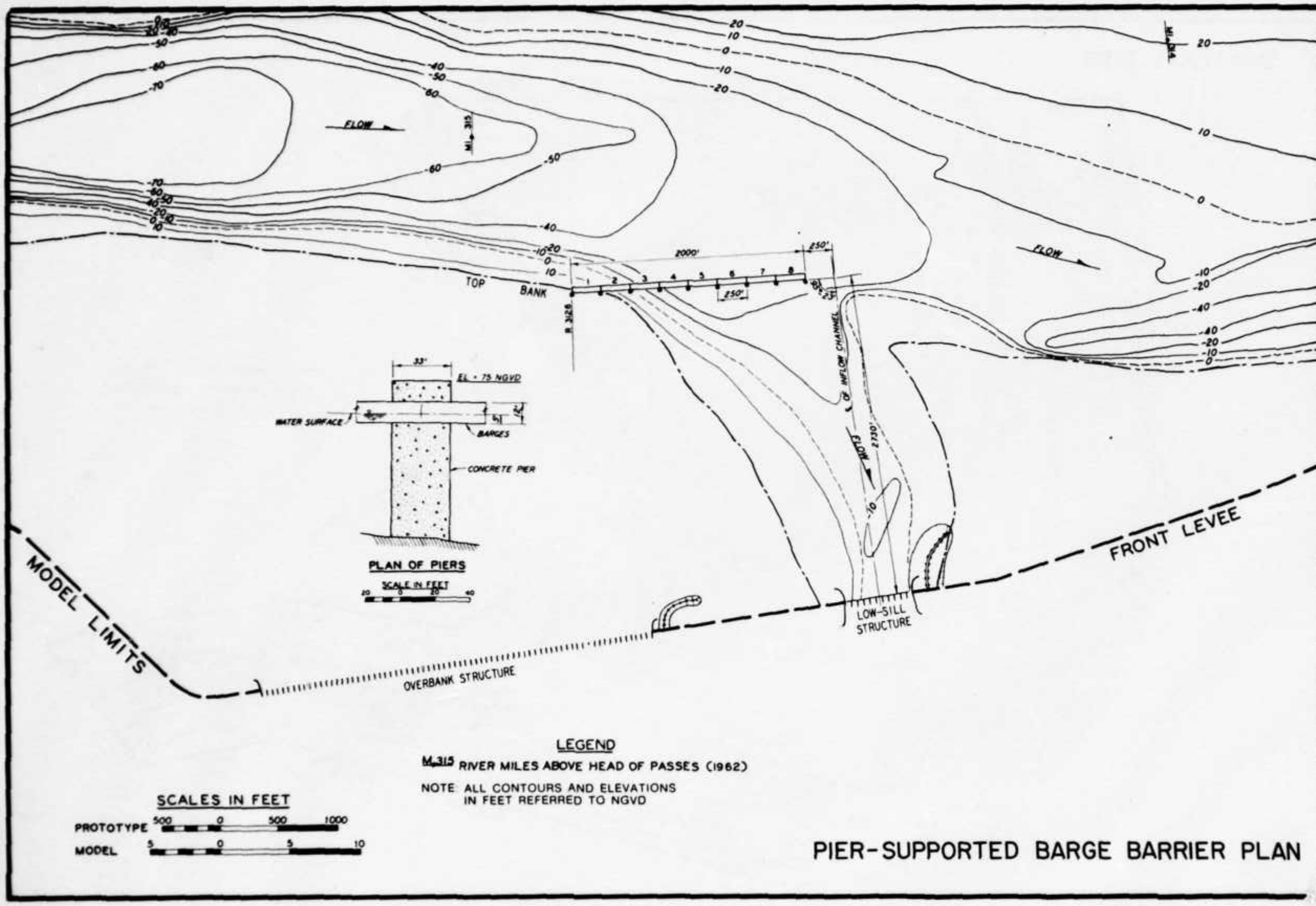
NOTE: ALL CONTOURS AND ELEVATIONS IN FEET NGVD

SCALES IN FEET

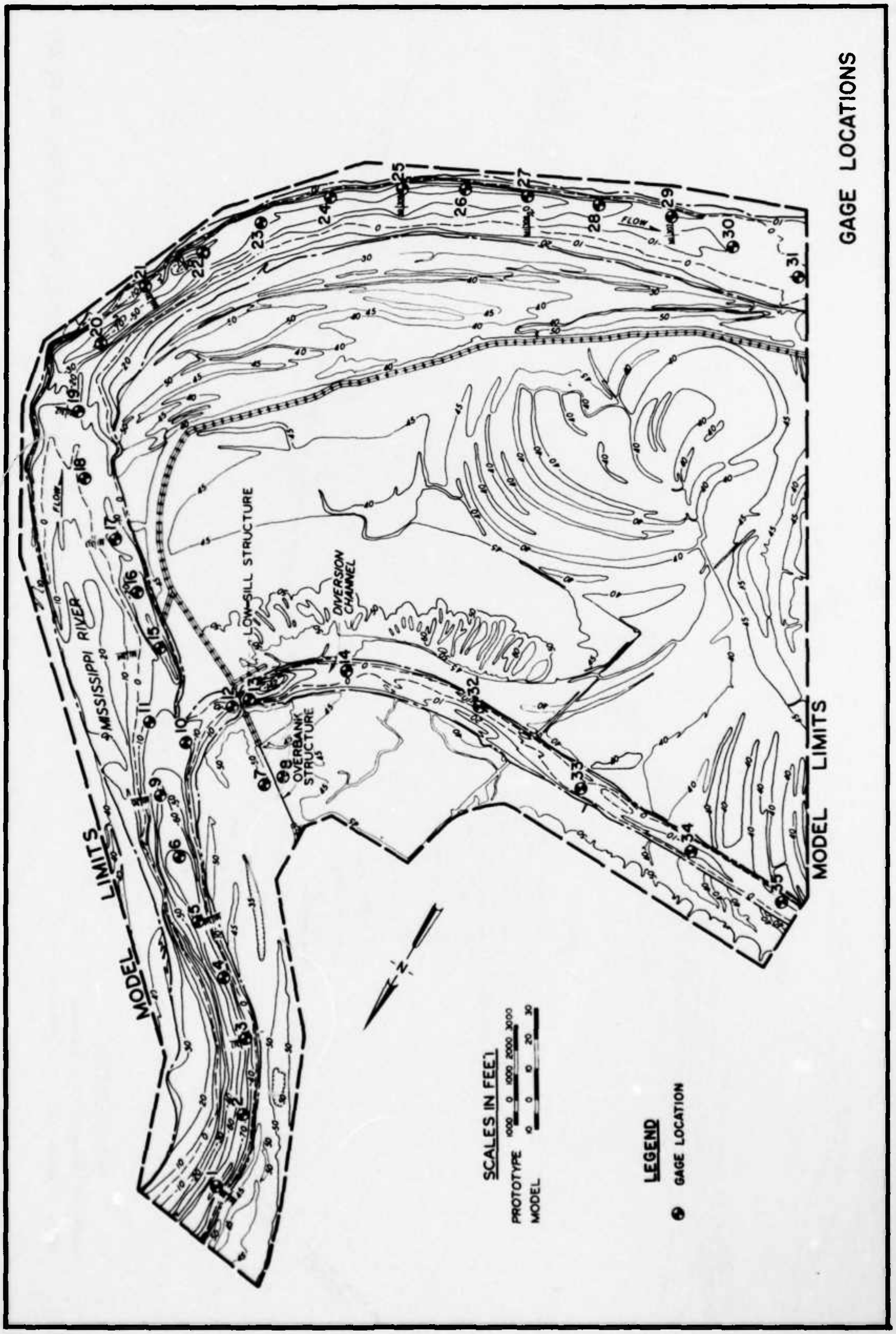
PROTOTYPE 500 0 500 1000

MODEL 5 0 5 10

VANE DIKE SYSTEM PLAN



PIER-SUPPORTED BARGE BARRIER PLAN



GAGE LOCATIONS

PLATE 4

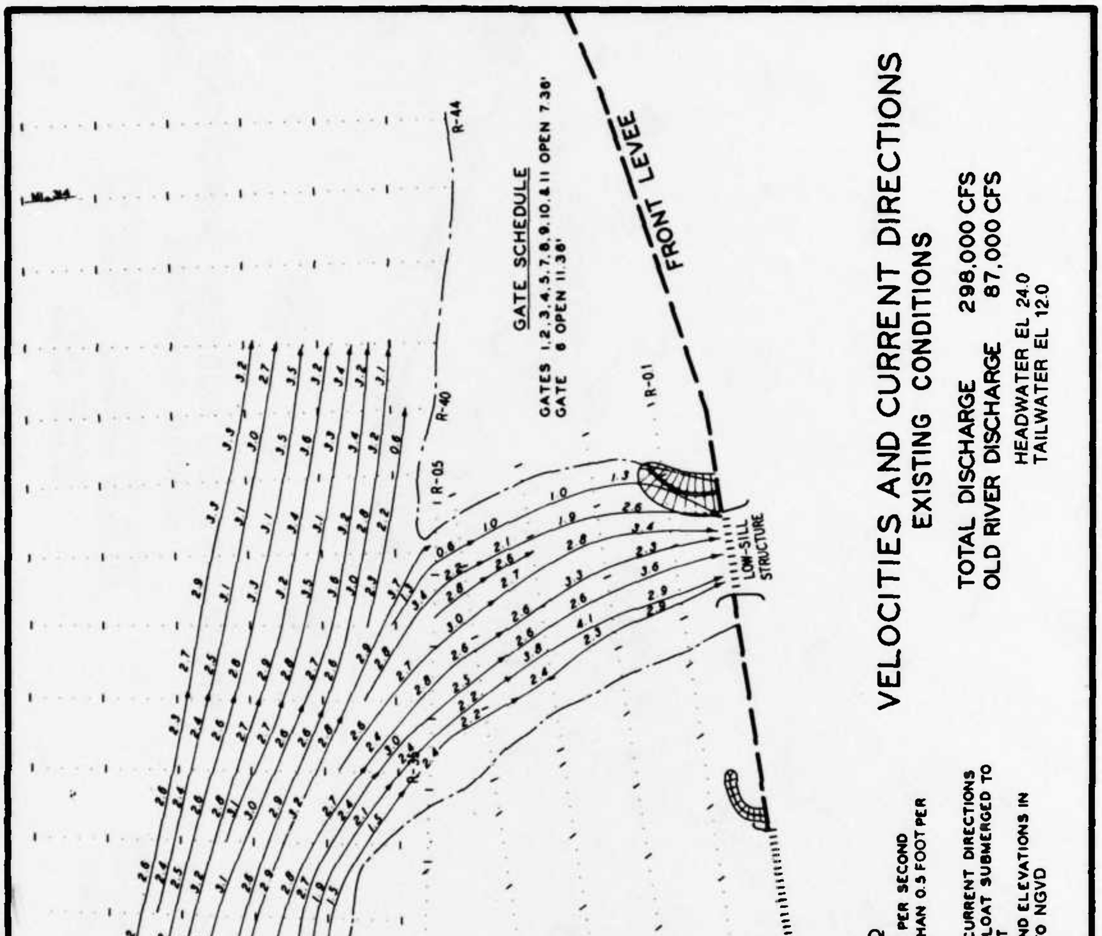
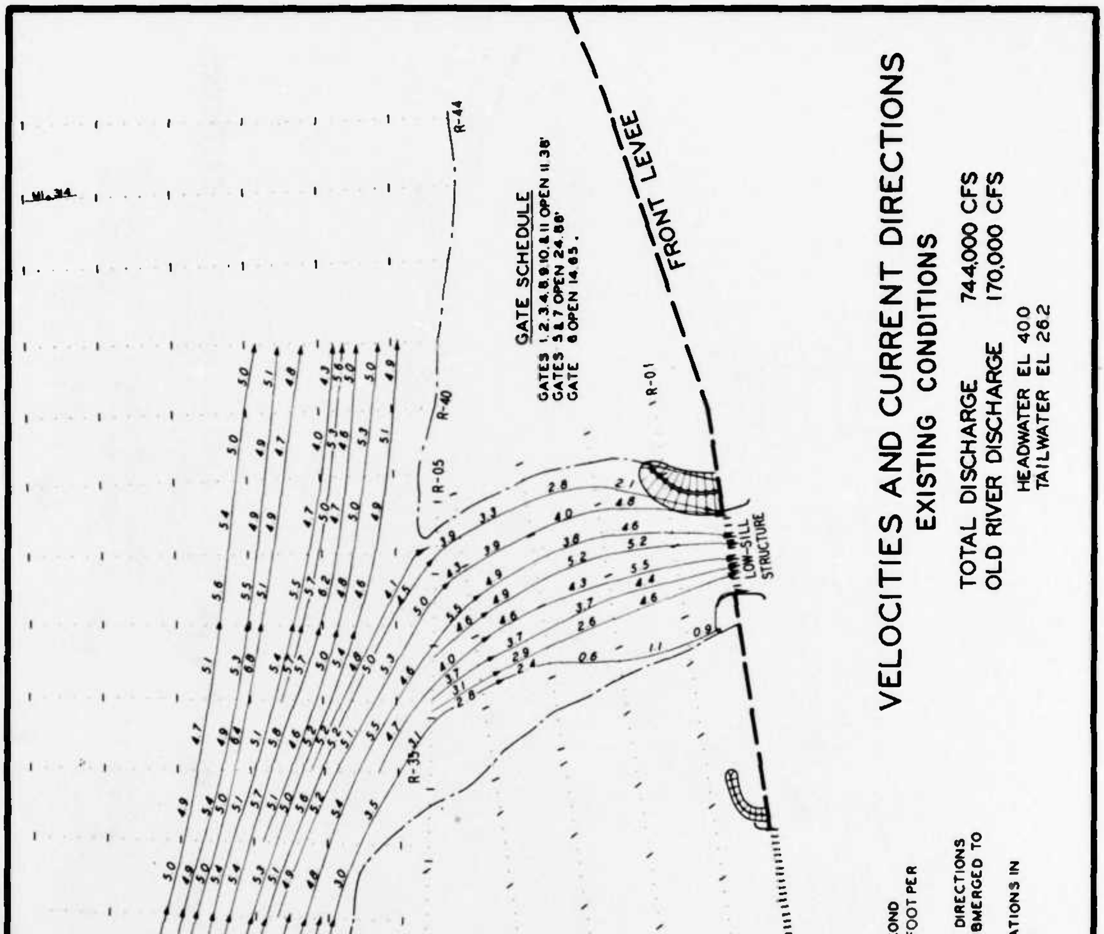
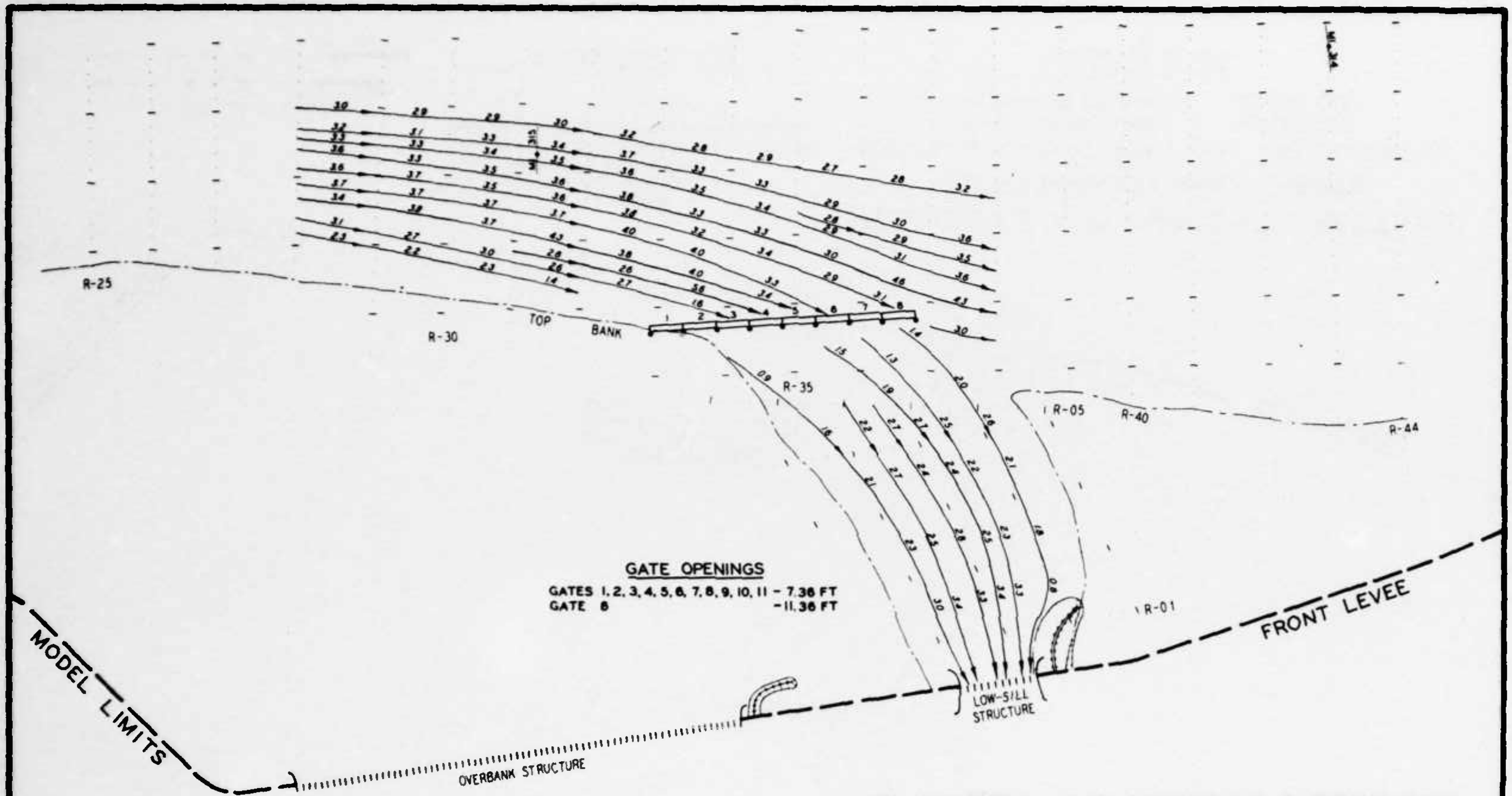

VELOCITIES AND CURRENT DIRECTIONS
EXISTING CONDITIONS
TOTAL DISCHARGE 298,000 CFS
OLD RIVER DISCHARGE 87,000 CFS
HEADWATER EL 24.0
TAILWATER EL 12.0
GATE SCHEDULE
GATES 1,2,3,4,5,7,8,9,10,& 11 OPEN 7.38'
GATE 6 OPEN 11.38'
FRONT LEVEE
LOW-SILL STRUCTURE
OVERBANK STRUCTURE
MODEL LIMITS
TOP BANK
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FOOT PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF 8.0 FEET
ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE
MODEL
R-25
R-30
R-40
R-44
R-05
R-01

PLATE 5



VELOCITIES AND CURRENT DIRECTIONS
EXISTING CONDITIONS
TOTAL DISCHARGE 744,000 CFS
OLD RIVER DISCHARGE 170,000 CFS
HEADWATER EL 40.0
TAILWATER EL 26.2
GATE SCHEDULE
GATES 1,2,3,4,8,9,10,& 11 OPEN 11.38'
GATES 5 & 7 OPEN 24.86'
GATE 6 OPEN 14.65'
FRONT LEVEE
LOW-SILL STRUCTURE
OVERBANK STRUCTURE
TOP BANK
MODEL LIMITS
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FOOT PER SECOND
NOTE VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF 9.0 FEET
ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE 500 0 500 1000
MODEL 5 0 5 10
R-25
R-30
R-35
R-40
R-44
R-05
R-01

PLATE 6



GATE OPENINGS

GATES 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 - 7.36 FT
GATE 8 - 11.36 FT

LEGEND

4.5 VELOCITY OBTAINED WITH FLOAT SUBMERGED TO NINE (9.0) FEET

VELOCITY LESS THAN 0.5 FOOT PER SECOND

M-315 RIVER MILES ABOVE HEAD OF PASSES (1962)

NOTE: ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD

SCALES IN FEET

PROTOTYPE 500 0 500 1000

MODEL 5 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

PIER-SUPPORTED BARGE BARRIER

LOW-SILL STRUCTURE OPERATION — ORIFICE CONTROL

TOTAL DISCHARGE 298,000 CFS

OLD RIVER DISCHARGE 89,000 CFS

HEADWATER EL 24.0

TAILWATER EL 12.0

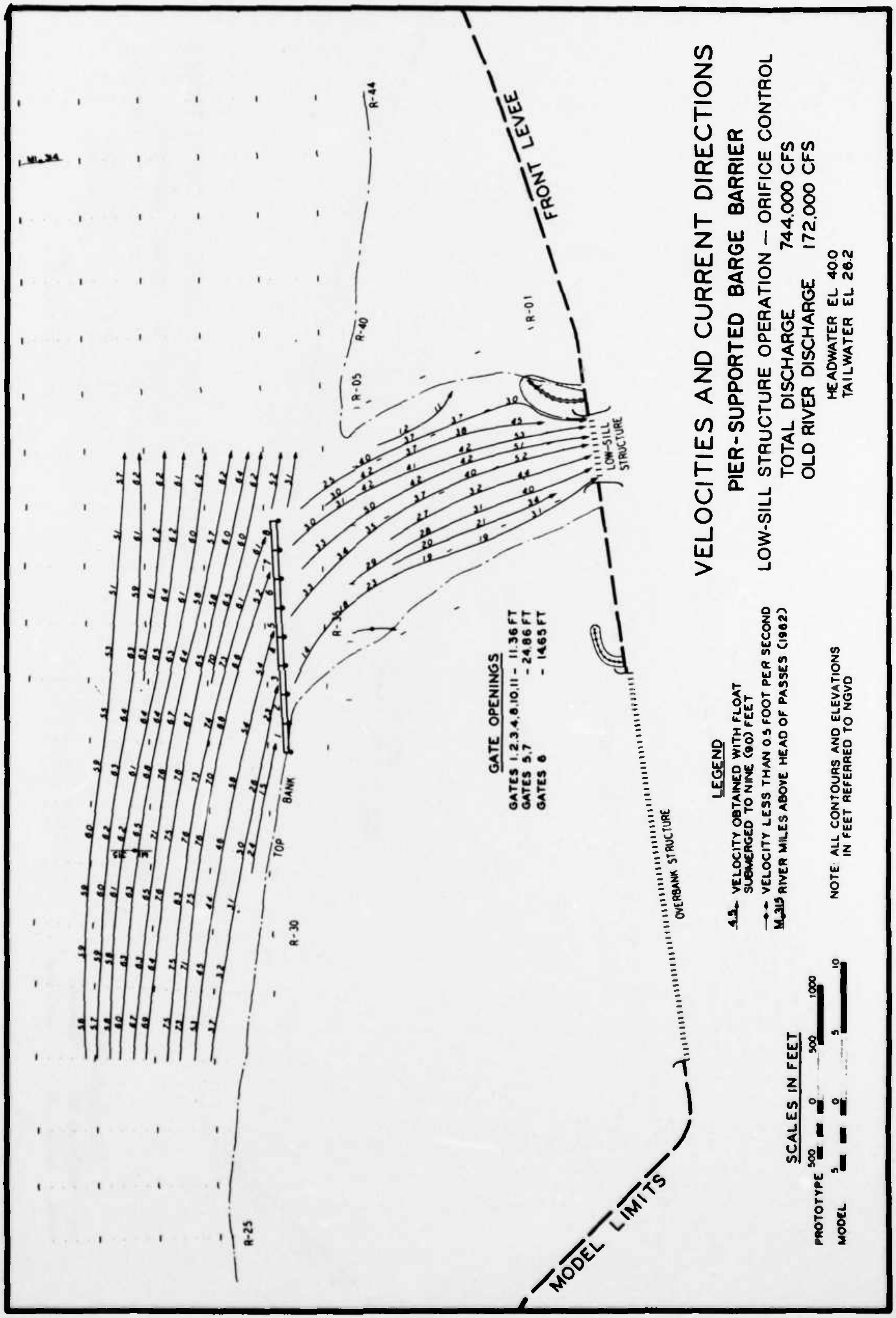
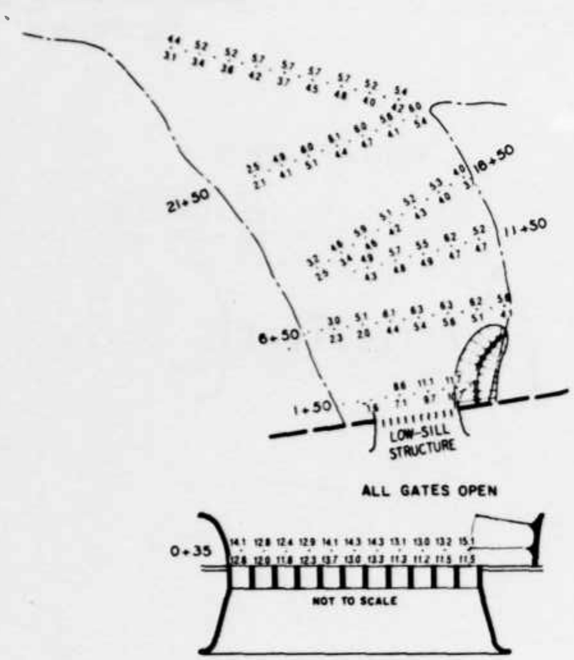
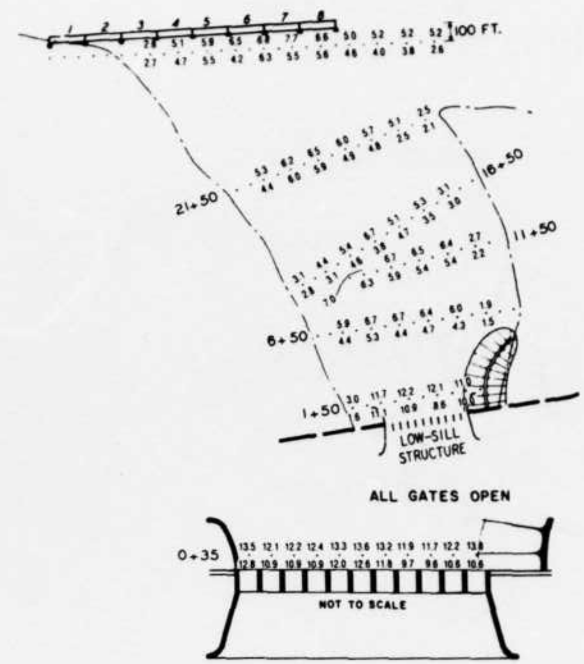

VELOCITIES AND CURRENT DIRECTIONS
PIER-SUPPORTED BARGE BARRIER
LOW-SILL STRUCTURE OPERATION — ORIFICE CONTROL
TOTAL DISCHARGE 744,000 CFS
OLD RIVER DISCHARGE 172,000 CFS
HEADWATER EL 40.0
TAILWATER EL 26.2
FRONT LEVEE
LOW-SILL STRUCTURE
OVERBANK STRUCTURE
TOP BANK
MODEL LIMITS
GATE OPENINGS
GATES 1,2,3,4,8,10,11 - 11.36 FT
GATES 5,7 - 24.86 FT
GATES 6 - 14.65 FT
LEGEND
VELOCITY OBTAINED WITH FLOAT SUBMERGED TO NINE (90) FEET
VELOCITY LESS THAN 0.5 FOOT PER SECOND
RIVER MILES ABOVE HEAD OF PASSES (1962)
NOTE: ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE
MODEL
R-25
R-30
R-40
R-44
R-05
R-01

PLATE 8



OLD RIVER DISCHARGE 358,000 CFS
HEADWATER EL 46.6
TAILWATER EL 42.7

EXISTING CONDITION



OLD RIVER DISCHARGE 358,000 CFS
HEADWATER EL 46.6
TAILWATER EL 42.7

PIER-SUPPORTED BARRIER

SCALES IN FEET

PROTOTYPE 500 0 500 1000

MODEL 5 0 5 10

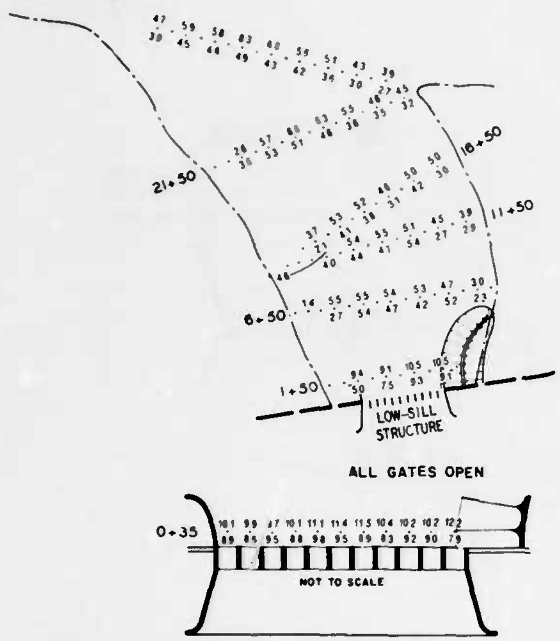
LEGEND

4.5 VELOCITY OBTAINED AT 0.6 DEPTH
2.3 VELOCITY OBTAINED AT BOTTOM DEPTH

NOTE: ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD

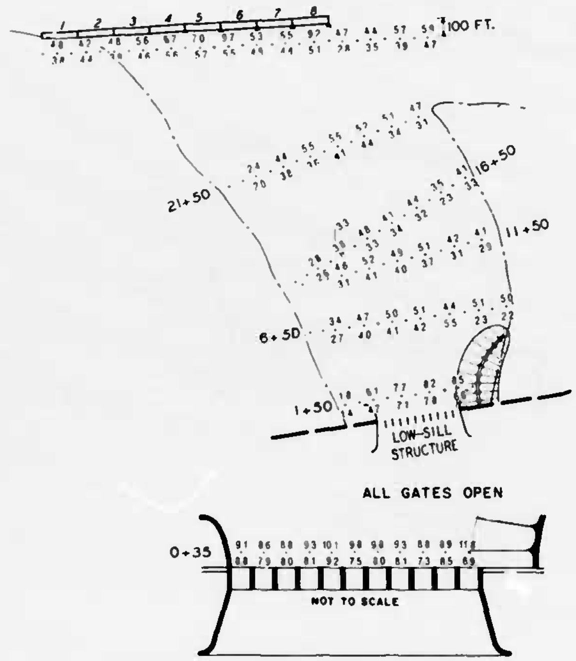
INFLOW CHANNEL VELOCITIES
BANK-FULL STAGE
TOTAL DISCHARGE 1,077,000 CFS

PLATE 10



OLD RIVER DISCHARGE 633,000 CFS
HEADWATER EL 62.1
TAILWATER EL 59.9

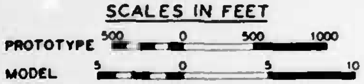
EXISTING CONDITION



OLD RIVER DISCHARGE 633,000 CFS
HEADWATER EL 62.1
TAILWATER EL 59.9

PIER-SUPPORTED BARRIER

SCALES IN FEET



LEGEND

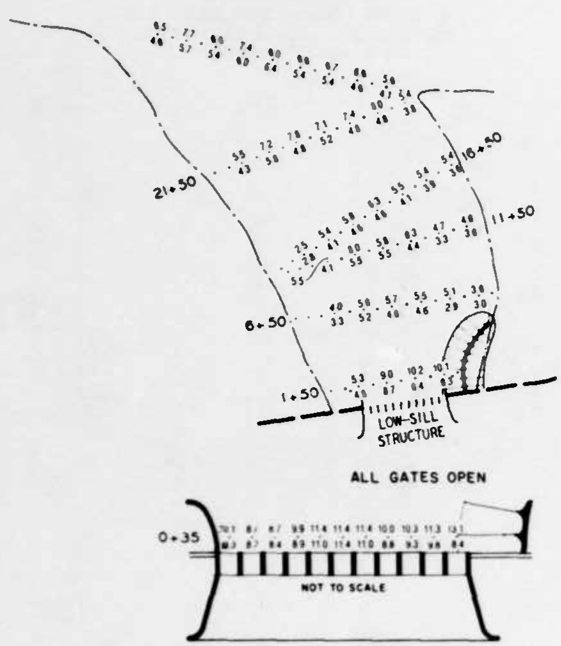
4.5 VELOCITY OBTAINED AT 0.6 DEPTH
2.3 VELOCITY OBTAINED AT BOTTOM DEPTH

NOTE: ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD

INFLOW CHANNEL VELOCITIES

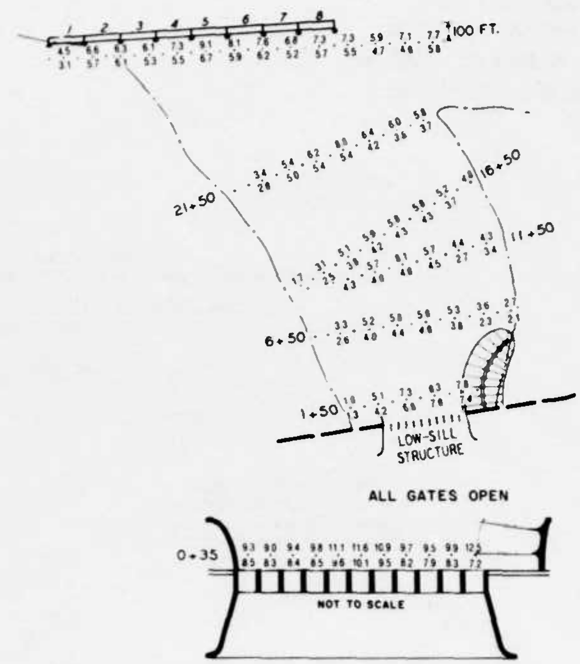
1973 FLOOD CREST

TOTAL DISCHARGE 1,970,000 CFS



OLD RIVER DISCHARGE 798,000 CFS
HEADWATER EL 69.5
TAILWATER EL 67.1

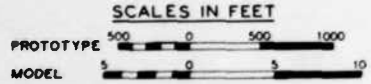
EXISTING CONDITION



OLD RIVER DISCHARGE 798,000 CFS
HEADWATER EL 69.5
TAILWATER EL 67.1

PIER-SUPPORTED BARRIER

SCALES IN FEET



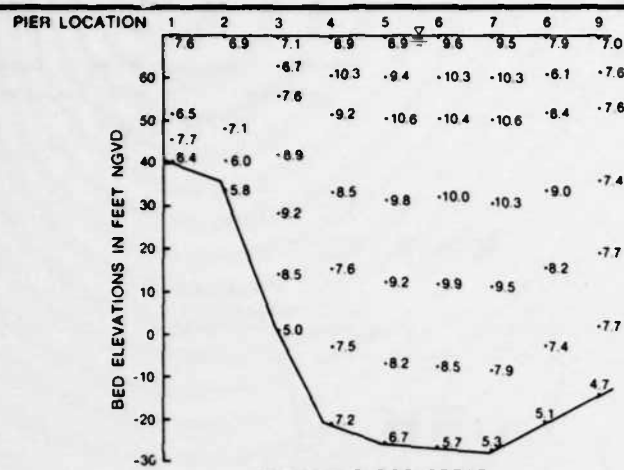
LEGEND

4.5 VELOCITY OBTAINED AT 0.6 DEPTH
2.3 VELOCITY OBTAINED AT BOTTOM DEPTH

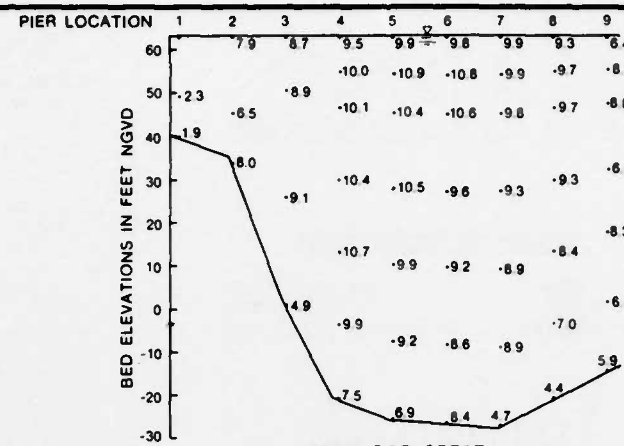
NOTE ALL CONTOURS AND ELEVATIONS IN FEET REFERRED TO NGVD

INFLOW CHANNEL VELOCITIES
PROJECT FLOOD CREST
TOTAL DISCHARGE 2,720,000 CFS

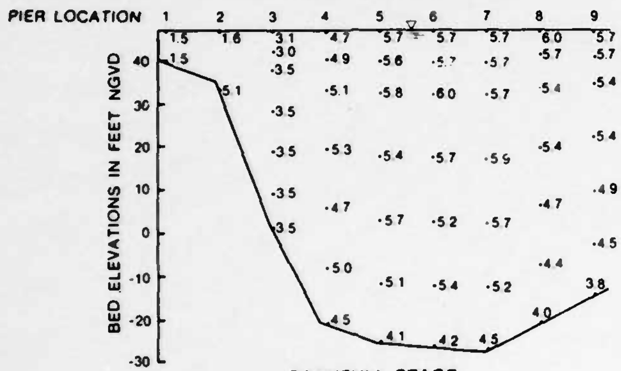
PLATE 11



PROJECT FLOOD CREST
TOTAL DISCHARGE - 2,720,000 CFS
OLD RIVER DISCHARGE 827,000 CFS
HEADWATER EL 68.8
TAILWATER EL 66.4



1973 FLOOD CREST
TOTAL DISCHARGE 1,972,000 CFS
OLD RIVER DISCHARGE 660,000 CFS
HEADWATER EL 61.8
TAILWATER EL 59.2



BANKFULL STAGE
TOTAL DISCHARGE 1,077,000 CFS
OLD RIVER DISCHARGE 358,000 CFS
HEADWATER EL 46.6
TAILWATER EL 42.7

LEGEND

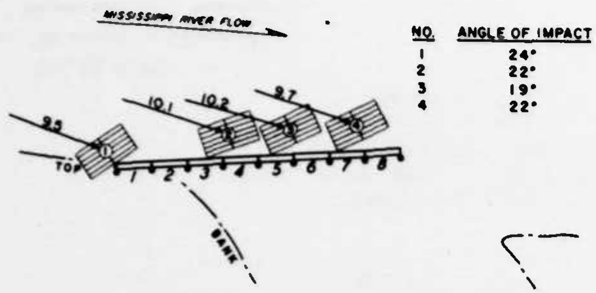
· 6.8 LOCATION AND VELOCITY IN FEET PER SECOND.

NOTE: VELOCITIES OBTAINED AT SURFACE, 0.1, 0.2, 0.4, 0.6, 0.8, AND BOTTOM DEPTHS.

NOTE: ALL LOW-SILL AND OVERBANK STRUCTURE GATES OPEN.

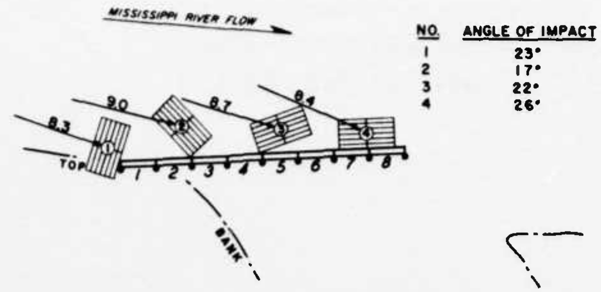
PIER-SUPPORTED
BARGE BARRIER TEST
POINT VELOCITIES AT
PIER LOCATIONS

PLATE 12



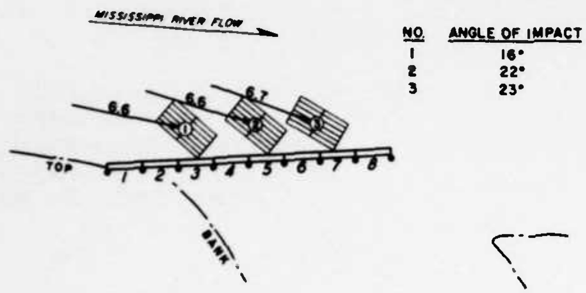
NO.	ANGLE OF IMPACT
1	24°
2	22°
3	19°
4	22°

PROJECT FLOOD CREST
TOTAL DISCHARGE 2,720,000 CFS
OLD RIVER DISCHARGE 798,000 CFS
HEADWATER EL 69.5
TAILWATER EL 67.1



NO.	ANGLE OF IMPACT
1	23°
2	17°
3	22°
4	26°

1973 FLOOD CREST
TOTAL DISCHARGE 1,972,000 CFS
OLD RIVER DISCHARGE 633,000 CFS
HEADWATER EL 62.1
TAILWATER EL 59.9



NO.	ANGLE OF IMPACT
1	16°
2	22°
3	23°

BANK-FULL STAGE
TOTAL DISCHARGE 1,077,000 CFS
OLD RIVER DISCHARGE 356,000 CFS
HEADWATER EL 46.5
TAILWATER EL 42.6

LEGEND

6.5 → VELOCITY OF IMPACT IN FEET PER SECOND

NOTE: ALL LOW-SILL AND OVERBANK STRUCTURE GATES OPEN.

SCALES IN FEET

LOOSE BARGE IMPACT TESTS
PIER-SUPPORTED BARGE BARRIER
12 BARGES - 6 WIDE, 2 LONG

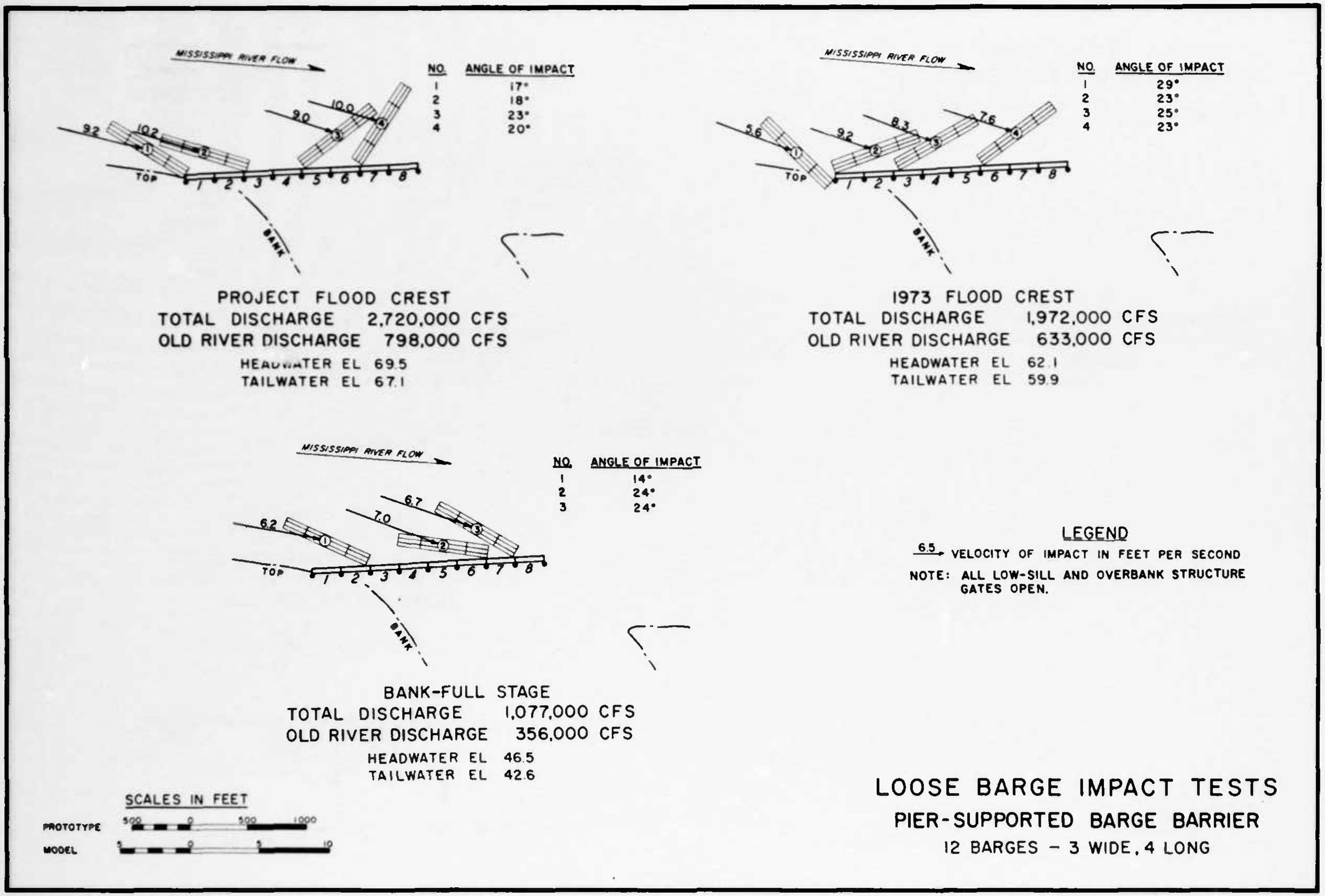

MISSISSIPPI RIVER FLOW
NO. ANGLE OF IMPACT
1 17°
2 18°
3 23°
4 20°
9.2
10.2
9.0
10.0
TOP
BANK
PROJECT FLOOD CREST
TOTAL DISCHARGE 2,720,000 CFS
OLD RIVER DISCHARGE 798,000 CFS
HEADWATER EL 69.5
TAILWATER EL 67.1
MISSISSIPPI RIVER FLOW
NO. ANGLE OF IMPACT
1 29°
2 23°
3 25°
4 23°
5.6
9.2
8.3
7.6
TOP
BANK
1973 FLOOD CREST
TOTAL DISCHARGE 1,972,000 CFS
OLD RIVER DISCHARGE 633,000 CFS
HEADWATER EL 62.1
TAILWATER EL 59.9
MISSISSIPPI RIVER FLOW
NO. ANGLE OF IMPACT
1 14°
2 24°
3 24°
6.2
7.0
6.7
TOP
BANK
BANK-FULL STAGE
TOTAL DISCHARGE 1,077,000 CFS
OLD RIVER DISCHARGE 356,000 CFS
HEADWATER EL 46.5
TAILWATER EL 42.6
LEGEND
6.5 VELOCITY OF IMPACT IN FEET PER SECOND
NOTE: ALL LOW-SILL AND OVERBANK STRUCTURE GATES OPEN.
SCALES IN FEET
PROTOTYPE 500 0 500 1000
MODEL 5 0 5 10
LOOSE BARGE IMPACT TESTS
PIER-SUPPORTED BARGE BARRIER
12 BARGES - 3 WIDE, 4 LONG

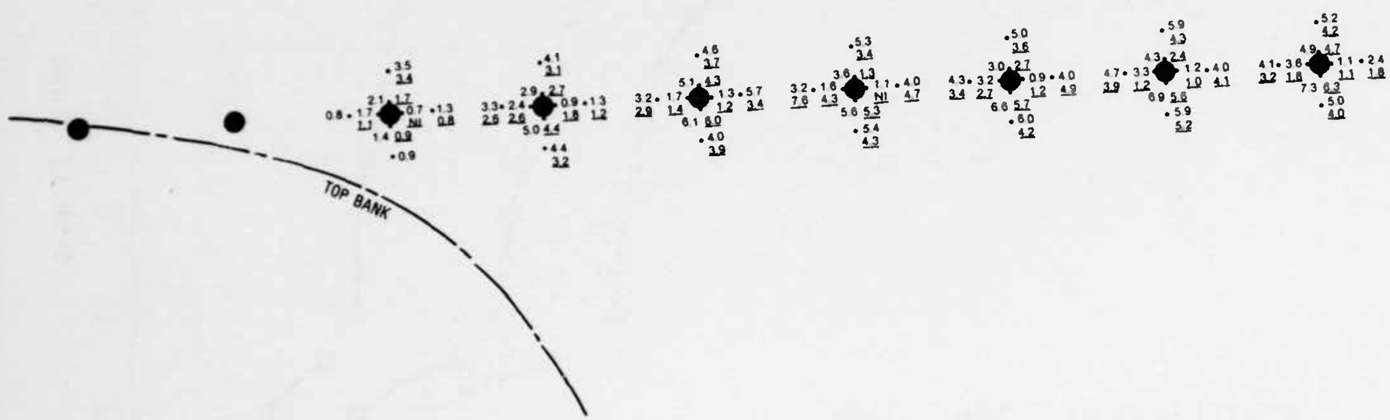
PLATE 14

LEGEND

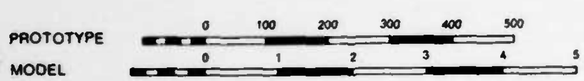
3.5 VELOCITY IN FEET PER SECOND AT 0.6 DEPTH
2.3 VELOCITY IN FEET PER SECOND AT BOTTOM
NI NO INDICATION OF VELOCITY

NOTE: BARRIER BARGES WERE IN PLACE WHEN THE VELOCITIES WERE OBTAINED, BUT ARE NOT SHOWN.

MISSISSIPPI RIVER FLOW

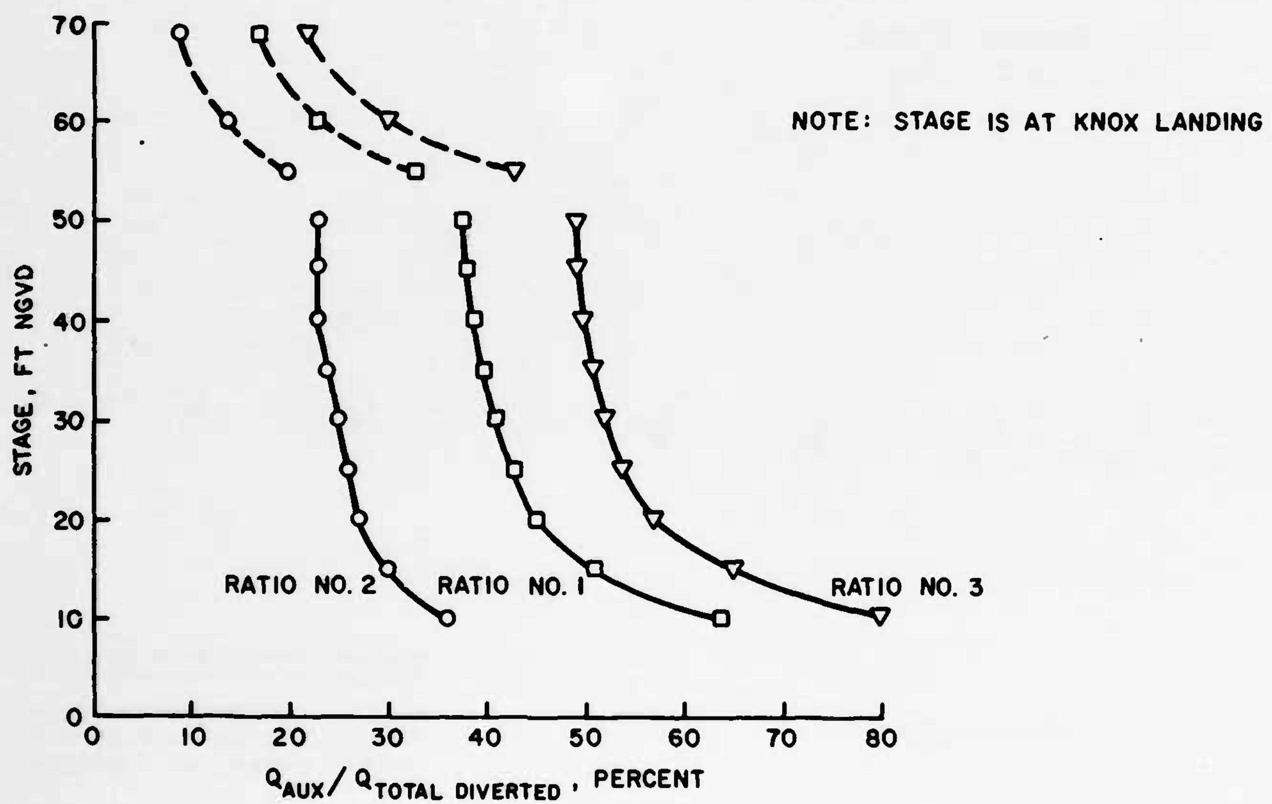


SCALES IN FEET



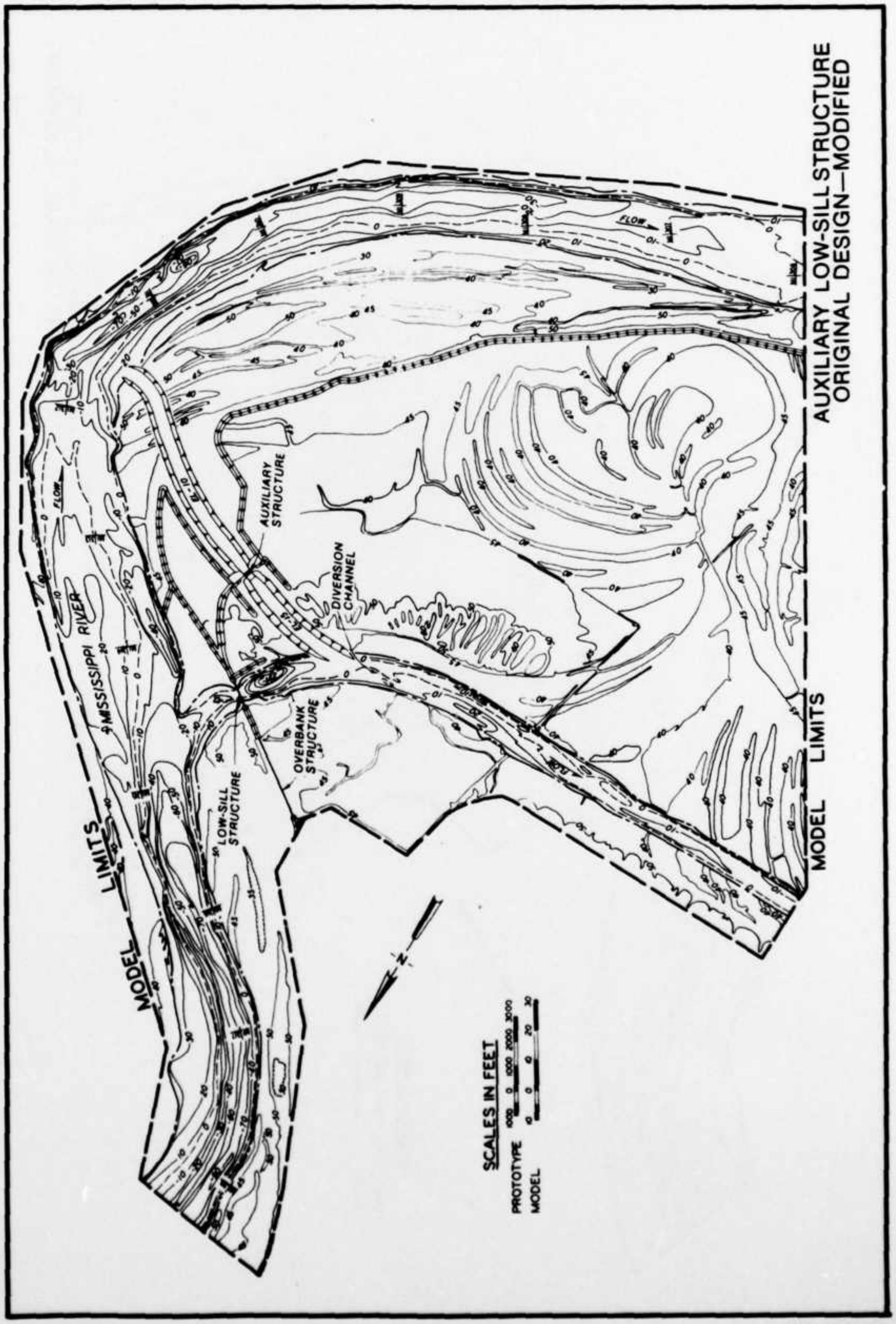
PIER-SUPPORTED BARGE BARRIER TEST

MISSISSIPPI RIVER DISCHARGE 744,000 CFS
OLD RIVER DISCHARGE 177,000 CFS
HEADWATER EL 40.0
TAILWATER EL 26.2



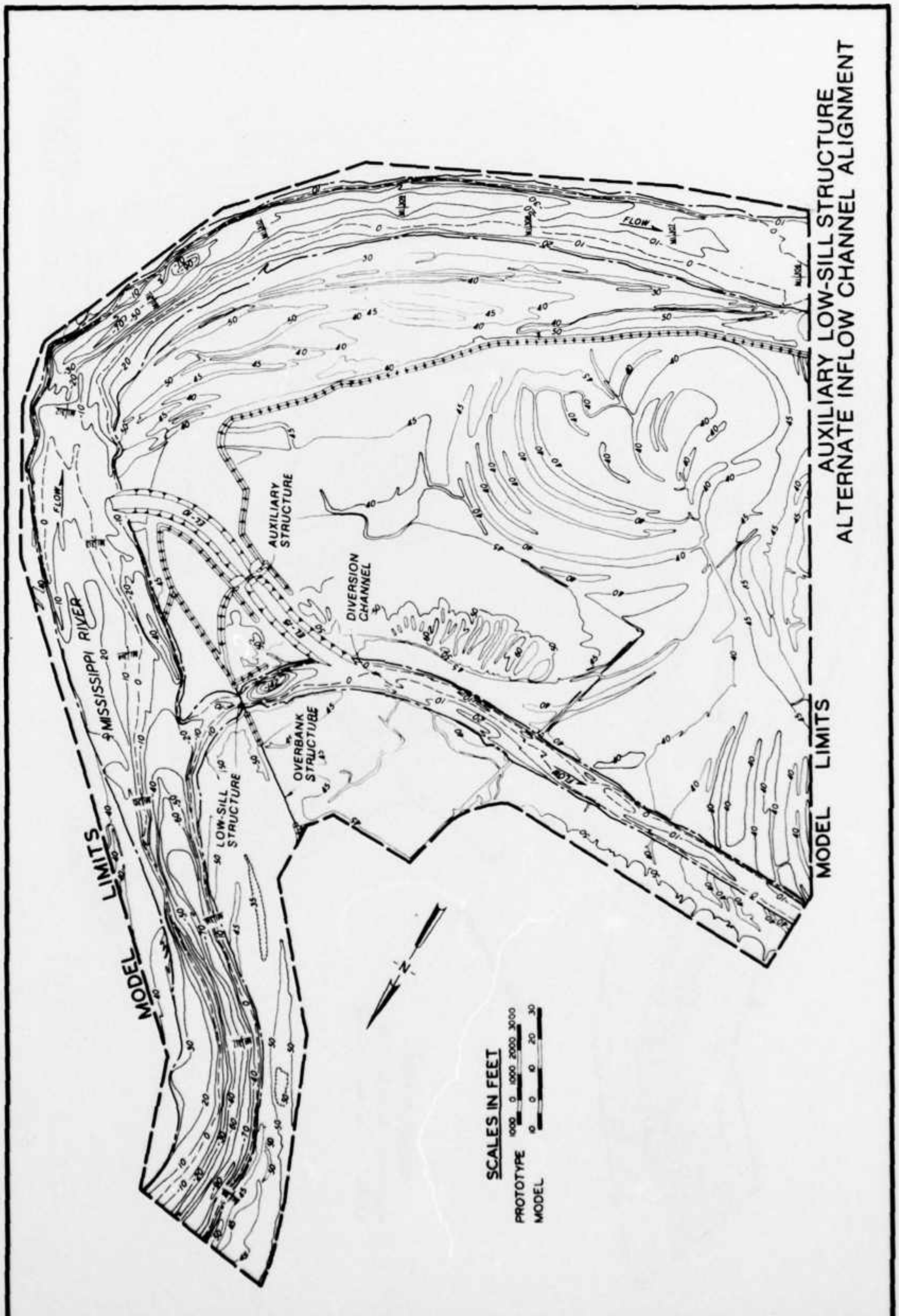
DISCHARGE DIVERSION RATIO CURVES
AUXILIARY STRUCTURE

PLATE 16



AUXILIARY LOW-SILL STRUCTURE
ORIGINAL DESIGN—MODIFIED

PLATE 17



AUXILIARY LOW-SILL STRUCTURE
ALTERNATE INFLOW CHANNEL ALIGNMENT

PLATE 18

DATE
ILME